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Detection and Interpretation of Trends in Oxidant Air Quality

Pacific Environmental Services, Inc.
Santa Monica, CA

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

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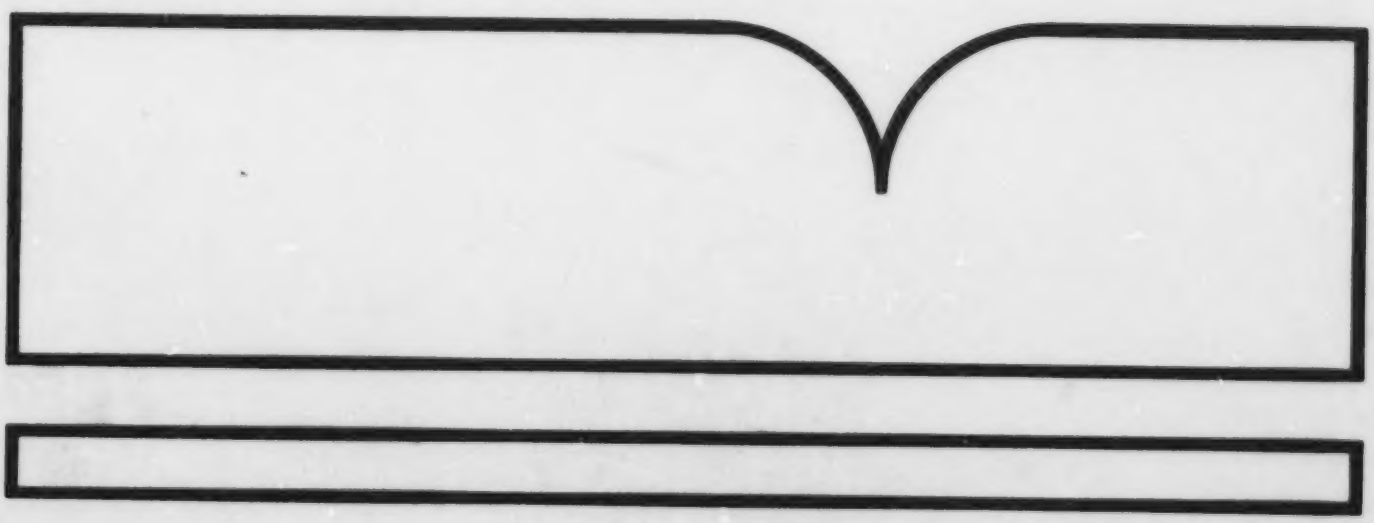

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DETECTION AND INTERPRETATION OF TRENDS IN OXIDANT AIR QUALITY

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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16. ABSTRACT

Trends in ambient levels of oxidants over periods of five years or more are reviewed for seven locations in the United States. Statistically significant downward trends were identified in the San Francisco Bay Area and in Denver. Trends in emissions of organic and NOx precursors over comparable periods are also reviewed. Only in San Francisco were the data sufficient to note a statistically significant relationship between precursor emission trends and the trend in ambient oxidant. Downward oxidant trends are most pronounced in the western part of the Bay area. Indications are that a five year period may not be sufficient to identify statistically significant trends in many areas. Downward trends in the Bay Area are much more pronounced when 13 years of records are examined.

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by

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Santa Monica, California 90404

Contract No. 68-02-1890
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Office of Air and Waste Management
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October 1976

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EXECUTIVE SUMMARY

This document presents a study of trends in oxidant air quality and their relation to trends in the emissions of oxidant precursors (namely, hydrocarbons and oxides of nitrogen), utilizing information from locations for which relevant data were available, representing five or more years of essentially continuous air monitoring.

Locations reviewed include five in California (not including the South Coast Air Basin), one in Colorado and one in Pennsylvania. Statistically significant trends in oxidant air quality were detected from the data only for the San Francisco Bay Area (California) and for the Metropolitan Denver Air Quality Control Region (Colorado). For both of these areas, the data yielded convincing evidence of trends toward lower oxidant concentrations over periods of five years or more. For the other locations reviewed, indications of trends were found, but the evidence was not unequivocal. An auxiliary analysis showed that oxidant air quality is not uniform throughout the San Francisco Bay Area Air Basin and that there are important differences in air quality related to the geographical distribution of stations with the Basin.

Comparing oxidant trends to trends in emissions of the precursors (hydrocarbons and oxides of nitrogen), the evidence showed that a nearly steady reduction of oxidant levels in the San Francisco Bay Area during the years from 1962-1974 was associated with a substantial decline of hydrocarbon emissions and a simultaneous major increase in the emissions of oxides of nitrogen, both consequences mainly of changes in emissions from mobile sources resulting from motor vehicle pollution control programs.

It was not possible to interpret the reasons for the significant improvement of air quality in the Denver area in terms of trends in the emissions of precursors, partly because of limitations of the data base for precursor emissions.

Within the single meteorological system which includes the San Francisco Bay Area and the Central Valley of California, oxidant problems were found to be most severe at inland valley locations and least severe in populous, industrial Bayside communities. These conditions seem to be related to two principal factors: the superior ventilation of communities along the main waterfronts, and the local oxidant-reducing effect (in such communities) of the oxides of nitrogen emitted by the more concentrated industry and motor vehicle traffic. Both of these protective circumstances tend to fade as the marine air moves downwind to inland valley locations.

To recapitulate, the main conclusions resulting from this project are:

1. Long-term trends in oxidant air quality in the San Francisco Bay Area are significantly related to trends in hydrocarbon emissions.

2. Oxidant concentrations in the San Francisco Bay Area are inversely affected by oxides of nitrogen emissions; thus, reduction of these emissions tends to increase measured oxidant levels, on the whole.

3. In the San Francisco Bay Area, oxidant problems tend to be more severe in inland valley locations than in industrial, Bayside locations.

4. The oxidant air quality of communities in the Central Valley of California is appreciably affected by the flow of polluted marine air from the adjacent San Francisco Bay Area.

5. Monitoring data for a five-year period is not, in general, sufficient to establish statistically significant oxidant trends for individual monitoring stations.

6. A significant reduction of oxidant levels occurred in Denver during the period 1968-1973. This cannot be attributed with confidence to observed trends in emissions.

7. The second highest daily high-hour oxidant value for a single year at a single station is a statistically useful measure of oxidant air quality.

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TABLE OF CONTENTS

Chapter		Page
	EXECUTIVE SUMMARY	1
	ACKNOWLEDGMENTS	iv
I.	INTRODUCTION	I-1
	RFFERENCES	I-3
II.	LOCATIONS SELECTED FOR STUDY	II-1
	A. INTRODUCTION	II-1
	B. THE SAN FRANCISCO BAY AREA	II-4
	1. PHYSICAL DESCRIPTION	II-4
	2. MONITORING STATIONS	II-8
	3. POPULATION AND GROWTH FACTORS	II-13
	4. INDUSTRY AND OTHER EMITTING ACTIVITIES	II-15
	C. REDDING (SACRAMENTO VALLEY AIR BASIN)	II-17
	1. PHYSICAL DESCRIPTION	II-17
	2. AIR MONITORING	II-18
	3. POPULATION AND GROWTH FACTORS	II-18
	4. INDUSTRY AND OTHER EMITTING ACTIVITIES	II-18
	D. STOCKTON AND MODESTO (SAN JOAQUIN VALLEY AIR BASIN)	II-20
	1. PHYSICAL DESCRIPTION	II-20
	2. AIR MONITORING	II-20
	3. POPULATION AND GROWTH FACTORS	II-21
	4. INDUSTRY AND OTHER EMITTING ACTIVITIES	II-22
	E. SALINAS (NORTH CENTRAL COAST AIR BASIN)	II-23
	1. PHYSICAL DESCRIPTION	II-23
	2. AIR MONITORING	II-25
	3. POPULATION AND GROWTH FACTORS	II-25
	4. INDUSTRY AND OTHER EMITTING ACTIVITIES	II-25
	F. LANCASTER (SOUTHEAST DESERT AIR BASIN)	II-27
	1. PHYSICAL DESCRIPTION	II-27
	2. AIR MONITORING	II-28
	3. POPULATION AND GROWTH FACTORS	II-28
	4. INDUSTRY AND OTHER EMITTING ACTIVITIES	II-28
	G. DENVER, COLORADO	II-30
	1. PHYSICAL DESCRIPTION	II-30
	2. AIR MONITORING	II-30
	3. POPULATION AND GROWTH FACTORS	II-32
	4. INDUSTRY AND OTHER EMITTING ACTIVITIES	II-33

TABLE OF CONTENTS (continued)

Chapter		Page
	H. PHILADELPHIA, PENNSYLVANIA	II-34
	1. PHYSICAL DESCRIPTION	II-34
	2. AIR MONITORING	II-34
	3. POPULATION AND GROWTH FACTORS	II-34
	REFERENCES	II-36
III.	OXIDANT TREND ANALYSIS	III-1
	A. INTRODUCTION	III-1
	B. SECOND HIGHEST MAXIMUM	III-2
	C. AVERAGE MAXIMUM	III-2
	D. THIRD QUARTER AVERAGE MAXIMUM	III-5
	E. FREQUENCY EXCEEDING NAAQS LEVEL	III-7
	F. FREQUENCY EXCEEDING TWICE NAAQS LEVEL	III-7
	G. RELATIONS BETWEEN THE INDICES	III-7
	H. REVIEW AND CONCLUSIONS	III-14
	REFERENCES	III-18
IV.	OXIDANT:PRECURSOR RELATIONSHIPS	IV-1
	A. SOUTH COAST AIR BASIN, CALIFORNIA	IV-1
	B. REVIEW OF EMISSIONS AND TRENDS, 1970-1974	IV-3
	1. BAY AREA AIR POLLUTION CONTROL DISTRICT	IV-3
	2. REDDING (SACRAMENTO VALLEY AIR BASIN)	IV-10
	3. STOCKTON AND MODESTO (SAN JOAQUIN VALLEY AIR BASIN)	IV-12
	4. SALINAS (NORTH CENTRAL COAST AIR BASIN)	IV-18
	5. LANCASTER (LOS ANGELES COUNTY PORTION OF SOUTHEAST DESERT AIR BASIN)	IV-20
	6. DENVER, COLORADO (METROPOLITAN DENVER AIR QUALITY CONTROL REGION)	IV-24
	7. PHILADELPHIA	IV-24
	C. COMPARISON BETWEEN OXIDANT TRENDS AND EMISSION TRENDS, 1970-1974	IV-28
	1. SAN FRANCISCO BAY AREA	IV-28
	2. DENVER	IV-29
	3. OTHER AREAS INCLUDED IN STUDY	IV-30

TABLE OF CONTENTS (continued)

Chapter		Page
	D. REVIEW OF LONG TERM TRENDS, SAN FRANCISCO BAY AREA.....	IV-33
	REFERENCES.....	IV-41
V.	INTERACTIONS WITH WEATHER AND OTHER FACTORS.	V-1
	A. SAN FRANCISCO BAY AREA, WEATHER VARIABLES.....	V-1
	B. GEOGRAPHICAL EFFECTS, BAY AREA AND CENTRAL VALLEY.....	V-5
	REFERENCES.....	V-10
VI.	SUMMARY AND CONCLUSIONS.....	VI-1

LIST OF FIGURES

Figure		Page
II-1.	CALIFORNIA AIR BASINS.....	II-3
II-2.	BAY AREA AIR BASIN.....	II-5
II-3.	MAP OF THE SAN FRANCISCO BAY AREA.....	II-6
II-4.	(FIGURE DELETED).....	II-12
II-5.	LARGE STATIONARY SOURCES, BAY AREA AIR BASIN	II-16
II-6.	NORTH CENTRAL COAST AIR BASIN.....	II-24
II-7.	COLORADO AIR QUALITY CONTROL REGIONS.....	II-31
IV-1.	SMALLEST VALUE OF CORRELATION COEFFICIENT SIGNIFICANTLY DIFFERENT FROM ZERO.....	IV-36
V-1.	NORMAL FLOW PATTERN IN THE SUMMERTIME MARINE LAYER.....	V-6

TABLE OF CONTENTS (continued)

LIST OF TABLES

Table		Page
II-1.	LOCATIONS OF AIR QUALITY MONITORING STATIONS PROVIDING DATA USED IN STUDY.....	II-9
II-2.	POPULATION AND BUILDING ACTIVITY BY YEAR, 1970-1974.....	II-14
III-1.	OXIDANT LEVEL, 2ND HIGH BY YEAR, AND TREND DIRECTION.....	III-3
III-2.	TOTAL OXIDANT AVERAGE MAXIMA AND TREND DIRECTIONS.....	III-4
III-3.	OXIDANT 3RD QUARTER AVERAGE MAXIMA AND TREND DIRECTIONS.....	III-6
III-4.	FREQUENCIES OF EXCEEDING 0.08 ppm, AND TREND DIRECTIONS.....	III-8
III-5.	FREQUENCIES OF EXCEEDING 0.16 ppm HOURLY AVERAGE OXIDANT.....	III-9
III-6.	TREND DIRECTIONS FOR VARIOUS OXIDANT INDICES, AS SHOWN AT VARIOUS MONITORING STATIONS.....	III-10
III-7.	RANKINGS OF 12 CALIFORNIA MONITORING STATIONS ACCORDING TO VARIOUS OXIDANT AIR QUALITY INDICES..	III-13
III-8.	ANALYSIS OF VARIANCE OF SECOND HIGH OXIDANT LEVELS FOR 9 BAY AREA (MONITORING STATIONS, FIVE YEARS (1970-1974).....	III-15
IV-1.	POLLUTANT EMISSIONS BY YEAR, BAY AREA AIR POLLUTION CONTROL DISTRICT.....	IV-4
IV-2.	BAY AREA AIR POLLUTION CONTROL DISTRICT HYDROCARBON EMISSIONS BY COUNTY, 1974.....	IV-5
IV-3.	BAY AREA AIR POLLUTION CONTROL DISTRICT OXIDES OF NITROGEN EMISSIONS BY COUNTY, 1974.....	IV-7
IV-4.	MOBILE SOURCE EMISSION INDICES.....	IV-9
IV-5.	POLLUTANT EMISSIONS BY YEAR, SHASTA COUNTY PORTION OF SACRAMENTO VALLEY AIR BASIN.....	IV-11
IV-6.	MOBILE SOURCE EMISSION INDICES, REDDING.....	IV-13
IV-7.	POLLUTANT EMISSIONS BY YEAR, SAN JOAQUIN COUNTY...	IV-14
IV-8.	POLLUTANT EMISSIONS BY YEAR, STANISLAUS COUNTY....	IV-15

LIST OF TABLES (continued)

Table		Page
IV-9.	MOBILE SOURCE EMISSION INDICES, TWO CITIES IN SAN JOAQUIN VALLEY AIR BASIN	IV-17
IV-10.	POLLUTANT EMISSIONS BY YEAR, MONTEREY COUNTY	IV-19
IV-11.	MOBILE SOURCE EMISSION INDICES, SALINAS	IV-21
IV-12.	POLLUTANT EMISSIONS BY YEAR, LOS ANGELES COUNTY PORTION OF SOUTHEAST DESERT AIR BASIN	IV-22
IV-13.	MOBILE SOURCE EMISSIONS INDICES, LANCASTER	IV-23
IV-14.	HYDROCARBON EMISSIONS BY YEAR, PHILADELPHIA, PA	IV-25
IV-15.	NITROGEN OXIDE EMISSIONS BY YEAR, PHILADELPHIA, PA	IV-26
IV-16.	TREND DIRECTIONS FOR VARIOUS EMISSIONS INDICES AND VARIOUS AIR QUALITY INDICES, FOR FIVE CALIFORNIA LOCATIONS AND PHILADELPHIA	IV-31
IV-17.	AVERAGE HIGH-HOUR OXIDANT CONCENTRATIONS FOR DAYS WITH COMPARABLE TEMPERATURE AND INVERSION CONDITIONS (APRIL THROUGH OCTOBER SMOG SEASONS, 1962-1974)	IV-35
IV-18.	TREND DIRECTIONS FOR VARIOUS OXIDANT INDICES SHOWN AT VARIOUS MONITORING STATIONS, SAN FRANCISCO BAY AREA	IV-38
IV-19.	ESTIMATED EMISSIONS BY YEAR, SAN FRANCISCO BAY AREA AIR POLLUTION CONTROL DISTRICT, 1962-1974, AND COMBINED EMISSION INDICES, FOR HYDROCARBONS AND OXIDES OF NITROGEN	IV-39
V-1.	RANK CORRELATION COEFFICIENTS BETWEEN VARIOUS ANNUAL OXIDANT INDICES AND AVERAGE NUMBER OF SMOG-CONDUCIVE DAYS, FOR YEARS 1970 TO 1974	V-2
V-2.	RANK CORRELATION COEFFICIENTS BETWEEN VARIOUS ANNUAL OXIDANT INDICES AND ANNUAL AVERAGE MAXIMUM TEMPERATURE IN DOWNTOWN SAN FRANCISCO, FOR YEARS 1970 TO 1974	V-4

I. INTRODUCTION

As part of its mission to protect and enhance the Nation's air resources, the U.S. Environmental Protection Agency has established a program of regular review and reporting, through the Monitoring and Data Analysis Division, Office of Air Quality Planning and Standards, on trends in air quality and emissions on both a national and a regional basis.

The first such report,[1] published in 1973, recognized inadequacies in the data available for interpretation at that time and emphasized that a trends review could only portray a particular cross section of an evolving process rather than a final result.

In particular, in regard to trends in oxidant air quality, the 1973 Trends report concluded, "The limitations in these data make it impossible to reach a meaningful conclusion."

Since 1973 much work has been done and much progress made in evaluating trends in oxidant air quality. To further this task of evaluation and interpretation, the Monitoring and Data Analysis Division contracted with Pacific Environmental Services to identify, review and interpret oxidant air quality data and oxidant precursor emissions data for a variety of locations satisfying certain minimum criteria for relevance to the problem of quantifying the relations between air quality and emissions trends.

Under the contract (Task Order No. 1 of Basic Ordering Agreement No. 68-02-1890) PES was directed to search for locations which could furnish five or more years of ambient air data from oxidant or ozone monitoring, to develop trend lines for various indices of oxidant air quality, and to investigate the

relationship of these trend lines to the history of precursor emission control programs. The observed trends were to be interpreted with respect to such factors as:

- meteorological differences
- growth patterns and geographical differences
- NO_x emission trends or ambient data
- hydrocarbon reductions
- monitoring site locations
- information from photochemical smog studies
- theoretical chemical dynamics of smog
- other pertinent information

This document embodies the final report of the project carried out under the subject contract. Chapter II describes the locations which were selected for more detailed consideration on the basis of preliminary inquiries as to the availability of relevant data. Chapter III reviews the oxidant air quality data in detail and discusses the methodology and results of trend evaluation. Chapter IV describes the available data concerning emissions of hydrocarbons and oxides of nitrogen, and explores the relations between the oxidant air quality trends and the emissions data. Chapter V takes up the possible relation of oxidant air quality trends to other factors, especially meteorological and geographical differences. Finally, Chapter VI presents the summary and conclusions.

REFERENCES

1. The National Air Monitoring Program: Air Quality and Emissions Trends. Annual Report, August 1973. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

II. LOCATIONS SELECTED FOR STUDY

A. INTPODUCTION

Minimum requirements for data availability, as specified in the Statement of Work for Task Order #1, were five or more years of ambient air oxidant or ozone monitoring records, with concurrent information on the history of hydrocarbon emission control programs. Up to eight locations were to be reviewed in detail, but the South Coast Air Basin of California was excluded by the project officer because a report[1] of the desired scope had recently been published. Locations outside of California were to be reviewed and included, if sufficient data were available.

After review of information supplied by NEDS, SAROAD, and the California Air Resources Board, the following locations were selected for more detailed study:

- The San Francisco Bay Area, California
- Redding, in Shasta County, within the Sacramento Valley Air Basin, California
- The northern San Joaquin Valley, California, represented by Stockton, in San Joaquin County, and Modesto, in Stanislaus County
- The Salinas Valley, in Monterey County, within the North Central Coast Air Basin, California
- Lancaster, in Los Angeles County, within the Antelope Valley, a part of the Southeast Desert Air Basin, California
- Denver City and County, part of the Metropolitan Denver Air Quality Control Region, Colorado
- Philadelphia City and County, part of the Metropolitan Philadelphia Air Quality Control Region, Pennsylvania
- Whiteface Mountain, near Wilmington, Essex County, New York

Of the locations selected, five were in California, three in other states, namely, Colorado, Pennsylvania and New York. Three (San Francisco, Denver, Philadelphia) were in metropolitan areas, four (Redding, San Joaquin Valley, Salinas and Lancaster) were in rural agricultural areas, one (Whiteface) was in an isolated location away from population centers.

Because of the relative abundance of ozone and oxidant data in California, more than half the locations selected for study were in that state. Figure II-1 shows the outlines of California Air Basins superposed on a physiographic map of the state. The locations selected represent a wide variety of types, from a large metropolitan area with a population of almost 5 million persons, to a somewhat agricultural desert community with a low-density population of about 50,000. Two of the areas are coastal, three inland.

Of the three inland locations, two are in the rich agricultural Central Valley, which comprises the Sacramento Valley in the north and the San Joaquin Valley in the South. Redding is at the northernmost extreme of the Central Valley, while Stockton and Modesto are near the geographical center of the Central Valley and within the relatively near vicinity of the San Francisco metropolitan area.

Expected information from the Whiteface Mountain location was, unfortunately, never received, so detailed analysis was confined to the remaining seven locations. The principal relevant characteristics of these seven regions and their air monitoring stations are reviewed in the following sections of this chapter.

FIGURE II-1, CALIFORNIA AIR BASINS

B. THE SAN FRANCISCO BAY AREA

1. Physical Description

The Bay Area Air Pollution Control District (BAAPCD) covers covers all of seven counties and the southern portions of two other counties, for a total area of about 6,000 square miles. Of twelve monitoring stations operated by BAAPCD in 1970, nine were chosen to represent the urban region (see map, Figure II-2).

This urban region includes the following significant topographic features possibly relevant to the generation and transport of ozone. To the west of the San Francisco peninsula lies the Pacific Ocean, to the east various bays and rivers. The land area includes the Santa Cruz and the Diablo mountain ranges, the former a part of the San Francisco peninsula and the latter located to the southeast across the Bay. Other land areas include various lowlands, foothills, canyons and valleys. Largest of the inland valleys is the Santa Clara Valley, south and east of the Bay. The Livermore Valley is a smaller, isolated valley due east of the Bay. In the northeast, the delta of the Sacramento and San Joaquin Rivers forms a passage to the great Central Valley, which is outside of the Bay Area District. The general complexity of the terrain is indicated by the contours shown in Figure II-3.

Meteorologically, the San Francisco Bay Area and associated valleys constitute a well-defined zone somewhat broken into subparts in terms of wind climatology. Rather low hills, the influence of the large water areas of the bays, and a large influx of maritime air produce several well-defined wind patterns in the area.

Except during late September and October, and during hot spells in April, May or June, wind movement provides consistent ventilation in much of the Bay Area.

FIGURE II-2. BAY AREA AIR BASIN

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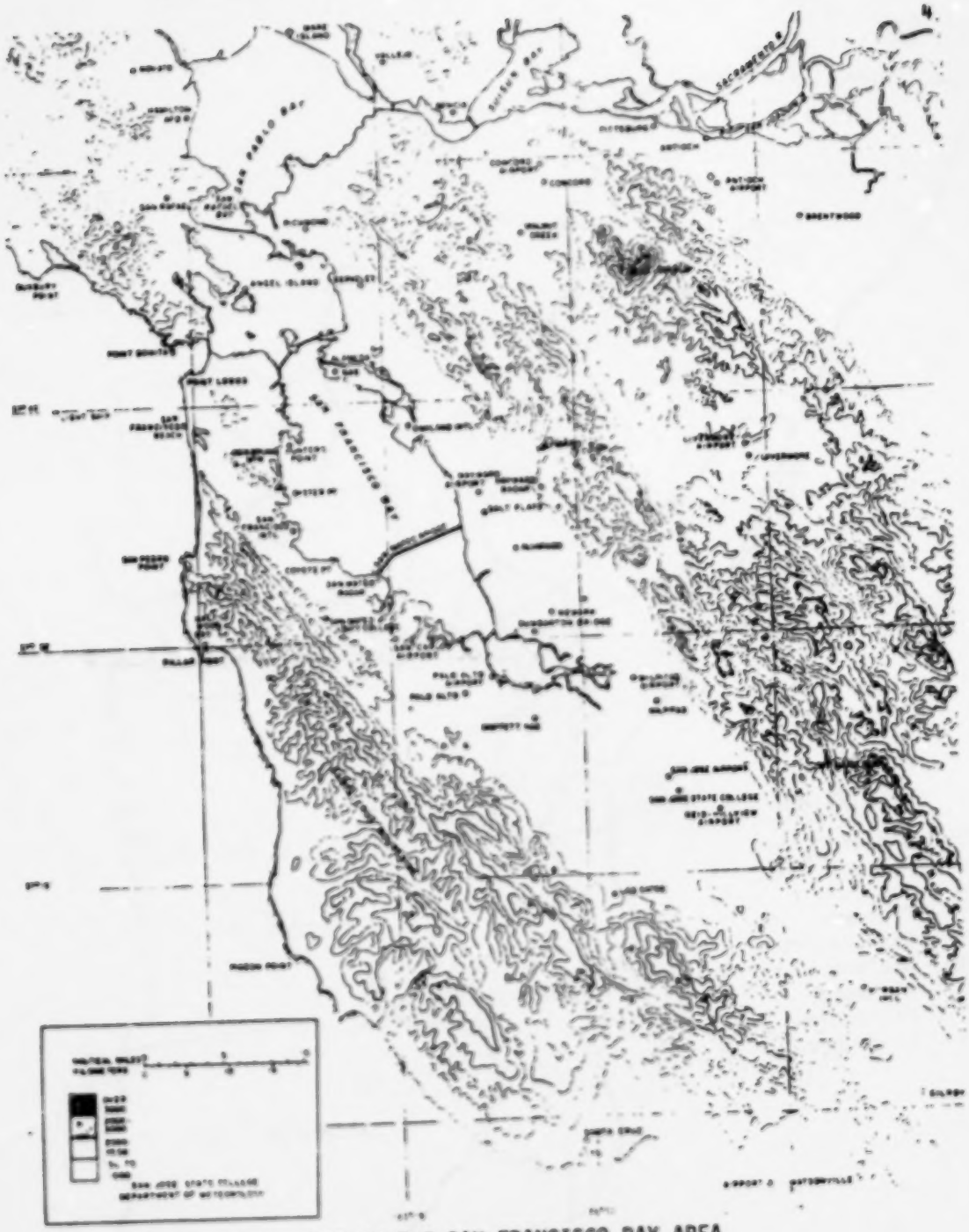

Figure II-3. MAP OF THE SAN FRANCISCO BAY AREA

Source: Ref. 2

During much of the year the winds from the sea divide to flow northward into the Sonoma and Napa valleys, eastward through the Carquinez Strait, and southward into the Santa Clara valley. This division of airflows makes the opposite ends of the Bay Area meteorological subparts of the region. The large flow of marine air through the Carquinez Strait has a marked influence upon the climate in portions of Solano and San Joaquin Counties.

As in other coastal areas, the subsidence inversion is dominant over this area most of the year. It varies seasonally and daily between 1,000 and 3,000 feet elevation. Due to solar heating, the inversion may be destroyed over the extreme ends of the Sonoma and Santa Clara valleys. Wide variations in vertical mixing occur over the extreme ends of these valleys.

Lovill and Miller (1968)[3] found that the maximum ozone in vertical profiles occurred above the inversion base and that it coincided with a wind jet in the inversion layer. Subsequently, Miller et al (1970)[4], concluded that the ozone within inversion layer comes from urban pollution by 2 routes: (1) by upward mixing from the crests of waves in the inversion base; (2) by vertical mixing in zones where the temperature inversion at its inland edge is destroyed by heating of the mixing layer, leaving ozone aloft when a new inversion is subsequently formed. At this inland edge the vertical temperature profile becomes unstable, and ozone concentrations have been observed to increase at altitudes as high as 2,000 meters.

From very recent work (San Jose State University, February, 1976) Miller[5] describes the inversion as having a mean base of 300 m ASL at Mt. Sutro (in San Francisco), with daily oscillations as much as $\pm$ 60m. The minimum height is reached in the late afternoon and the mixing occurs in predawn hours. The amplitude of oscillation at Oakland, on the east side of the bay, appears to be double that found at the Mt. Sutro tower. Ozone concentrations were invariably 5-10 times higher within the inversion layer than in the marine air below the inversion. Concentrations as high as 30 pphm have been observed

within the inversion layer when levels in the marine air were only 1-3 pphm. The inversion may extend Westward over the Pacific ocean as far as 100 Km.

Within the inversion layer at Mt. Sutro, Miller et al observed strong turbulence with rapid temperature and wind changes. The slope of the inversion is generally downward from west to east.

2. Monitoring Stations

For a fair representation of the air quality of the San Francisco Bay Area no single monitoring station would suffice, in view of the complexities of terrain and wind regimes discussed in the previous section. As a basis for statistical comparisons, PES selected for study the nine locations shown in Figure II-2. Coordinates and characteristics of the monitoring stations representing these communities are listed in Table II-1.

These locations are mainly in the more densely populated part of the Bay Area, along the southern and eastern shores of the Bay. Highest population densities are represented by San Francisco, Oakland, and San Jose. Relatively more suburban areas are Redwood City and Fremont; relatively more industrial areas are Richmond and San Leandro. Livermore represents a small, inland city in an isolated valley, while Pittsburg, another inland city, is situated near the rather flat Delta country, along the main channel between Suisun Bay and the Sacramento River.

Not all of the nine counties included in the Bay Area Air Pollution Control District are represented by this selection. In fact, four of the selected locations -- Oakland, San Leandro, Fremont, and Livermore -- are in one county, Alameda. Other counties represented are Contra Costa with two stations, Richmond and Pittsburg; San Francisco; San Mateo, with Redwood City: and Santa Clara, with San Jose. The unrepresented counties -- Marin, Sonoma, Napa and Solano -- are less

Table II-1. Locations of Air Quality Monitoring Stations Providing Data Used in Study

a. San Francisco (SF) -

Address: 939 Ellis St. - sample period 1/70-12/74
UTM Northing: 4181810
Easting: 550980
Station Type: Central City - Commercial
Elevation: Above Ground 104' above MSL 229'
Comment: Near Civic Center, close to a heavily traveled Boulevard.

b. Redwood City (RC)

Address: 897 Barron Ave. - sample period 1/70-12/74
UTM Northing: 4148560
Easting: 570549
Station Type: Suburban - Commercial
Elevation: Above Ground 14' above MSL 29'
Comment: In a residential and light industrial section south of the city. (Entire city is near a busy freeway.)

c. San Jose (SJ)

Address: 301 So. 5th Str. - sample period 1/70-5/70
UTM Northing: 4132150
Easting: 599120
Station Type: Center City - Commercial
Elevation: Above Ground 20' above MSL 109'

Address: 104 W. Alma - sample period 6/70-7/72
UTM Northing: 413027
Easting: 599770
Station Type: Center City - Commercial
Elevation: Above Ground 28' above MSL 136'
Comment: About two km from previous location.

Address: 1203 N. 4th St. - sample period 7/72-12/74
UTM Northing: 4132920
Easting: 598580
Station Type: Center City - Commercial
Elevation: Above Ground 28' above MSL 108'
Comment: About 4km from previous location, about 1 km from original location.

Table II-1 (cont) Locations of Air Quality Monitoring Stations Providing Data Used in Study

d. Fremont (FR)

Address: 3965 Union St. - sample period 1/70-12/70
UTM Northing: 4154310
Easting: 592060
Station Type: Center City - Commercial
Elevation: Above ground 20' above MSL 71'

Address: 40733 Chapel Way - sample period 1/71-12/74
UTM Northing: 4154620
Easting: 591880
Station Type: Suburban - Residential
Elevation: Above Ground 18' above MSL 78'
Comment: Farther from freeway than previous location.

e. San Leandro (SL)

Address: 850 Thornton - sample period: 1/70-12/74
UTM Northing: 4174690
Easting: 573960
Station Type: Center City - Industrial
Elevation: Above Ground 30' above MSL 80'
Comment: Near schools, parks, freeway

f. Oakland (OK)

Address: 1111 Jackson St., - sample period: 1/70-12/74
UTM Northing: 4183650
Easting: 564580
Station Type: Center City - Commercial
Elevation: Above Ground 118' above MSL 154'
Comment: Near Lake Merritt and city center

g. Richmond (RI)

Address: 1430 Nevin Ave. - sample period: 1/70-3/72
UTM Northing: 4198850
Easting: 556730
Station Type: Center City - Commercial
Elevation: Above Ground msg. above MSL msg.

Address: 1144 - 13th St., - sample period 3/72-12/74
UTM Northing: Latitude N 37^{o} 57' 00"
Easting: Longitude W 122^{o} 21' 21"
Station Type: Suburban - Industrial, Residential & Commercial
Elevation: Above ground 22.5' above MSL 76.5'

Table II-1 (cont) Locations of Air Quality Monitoring Stations Providing Data Used in Study

h. Pittsburg (PT)

Address: 583 W. Tenth St. - sample period: 1/70-12/74
UTM Northing: 4209500
Easting: 597100
Station Type: Center City - Commercial
Elevation: Above Ground 25' above MSL 30'
Comment: Not far from main river channel

i. Livermore (LV)

Address: 2500 Railroad Ave. - sample period: 1/70-12/74
UTM Northing: 4171230
Easting: 608850
Station Type: Center City - Commercial
Elevation: Above Ground 20' above MSL 504'
Comment: Well removed from freeway

populous and have not been provided with monitoring stations with the exception of one in San Rafael, Marin County.

In some of these communities, the monitoring facilities were relocated during the period of interest, 1970 to 1974. In San Jose there were two relocations, one after the first five months of 1970, and the second in July 1972, half way through the five-year period. In Fremont and in Richmond, one relocation occurred. To the extent that these moves may have changed the relation between the monitoring station and nearby contaminant sources such as freeways or busy intersections, they could introduce some bias into the determination of air quality trends. However, the number of such changes, for a nine station network, has been minimal.

3. Population and Growth Factors

Population in the Bay Area is centered around the San Francisco Bay with the greatest densities near the cities of San Francisco, Oakland and San Jose. The northern counties, Marin, Sonoma, Napa and Solano are relatively sparsely populated. Between 1970 and 1974 little or no population growth occurred in San Francisco city/county or in Alameda and San Mateo counties; in fact a 5% decrease has taken place in San Francisco. Contra Costa county increased 4% (20,900) with the increase spread over a dozen cities rather than concentrated in one location. Marin county population grew 3%, but this is equivalent to only 4500 persons. The greatest growth occurred in Santa Clara county (9% or 97,000) almost entirely in San Jose and nearby Sunnyvale.

Population figures are given in Table II-2. In addition, the numbers of building permits issued in each city are listed. In general, these figures parallel the population growth. In summary, there has been little growth in the Bay Area between 1970 and 1974 except at the southern tip of San Francisco Bay in the general area of San Jose, and even here the growth has amounted to less than 10% over this 5-year period.

Table II-2

Population* and Building Activity by Year, 1970 - 1974

County	Measure of Growth	1970	1971	1972	1973	1974
San Francisco	City/county population	712,100	709,000	695,800	692,800	679,200
	City building permits	1771	3476	3188	4148	1370
Marin	County population	207,000	209,200	211,500	214,100	211,500
	San Rafael population	38,949				44,850
	San Rafael building permits	124	716	1051	523	220
Contra Costa	County population	557,400	562,900	567,600	573,600	578,300
	Richmond population	79,088				74,700
	Richmond building permits	218	484	271	328	130
	Pittsburgh population	20,651				24,500
	Pittsburg building permits	261	639	1149	119	274
Alameda	County population	1,072,700	1,088,100	1,094,400	1,089,100	1,087,300
	Oakland population	361,613				339,600
	Oakland building permits	1969	1480	1829	1170	493
	Fremont population	100,875				115,600
	Fremont building permits	2191	3470	2730	979	592
	Livermore population	37,703				47,400
	Livermore building permits	857	1756	1401	508	101
Santa Clara	County population	1,072,400	1,093,600	1,122,000	1,146,900	1,169,400
	San Jose population	446,504				528,900
	San Jose building permits	9516	10,645	8014	7428	5097
San Mateo	County population	557,200	559,900	560,900	565,500	568,900
	Redwood City population	55,539				54,000
	Redwood City building permits	128	803	249	119	155
TOTAL APCD	POPULATION WITHIN AREA	4,526,000	4,624,000	4,667,000	4,706,000	4,729,000

* Data obtained from U. S. Bureau of the Census and from the California State Population Research Unit.

4. Industry and Other Emitting Activities

Most major industrial activity in the Bay Area is located on the eastern shore of San Francisco Bay in Alameda County, or along the shoreline of Contra Costa County, including the shores of Carquinez Strait and Suisun Bay, east of Richmond.

Oil refineries, chemical plants, and power plants are the major point sources of hydrocarbons and NO_x in Contra Costa county. Two auto assembly plants near the south end of the bay are large hydrocarbon emitters, and power plants on the bay near San Francisco emit large quantities of nitrogen oxides. These are shown on the map in Figure II-5. Historical records are not maintained on emissions from stationary sources, but no major changes have occurred either as a result of changes in emissions regulations or as a result plant shutdowns or openings. Regulations promulgated by BAAPCD for control of emissions from stationary sources remained essentially uniform throughout the period, 1970-1974. Open burning has been effectively curtailed since a control program was implemented in the period 1960 to 1965. There have, however, been numerous minor changes in the APCD regulations. Regulation 2, which deals with incineration, heat transfer and general fuel combustion sources, was first adopted in 1960; its current version is a twelfth revision, adopted in February 1975 and amended in March 1975. Regulation 3, limiting emissions of organic gases was adopted in 1967 and revised late in 1974. Regulation 4, requiring crankcase emission control on certain motor vehicles, went into effect in mid-1971. A regulation requiring recovery of vapors from gasoline marketing operations was adopted in 1973, but did not become effective until 1976.

Mobile source emissions trends are discussed below (Chapter IV). In general, hydrocarbon emissions from such sources decreased less than 10% in most areas with increases and decreases both being recorded. In San Jose, where growth was rapid, hydrocarbons increased about 20% between 1970 and 1974. Nitrogen oxides usually stayed constant or increased by no more than 20% except in San Jose where the increase

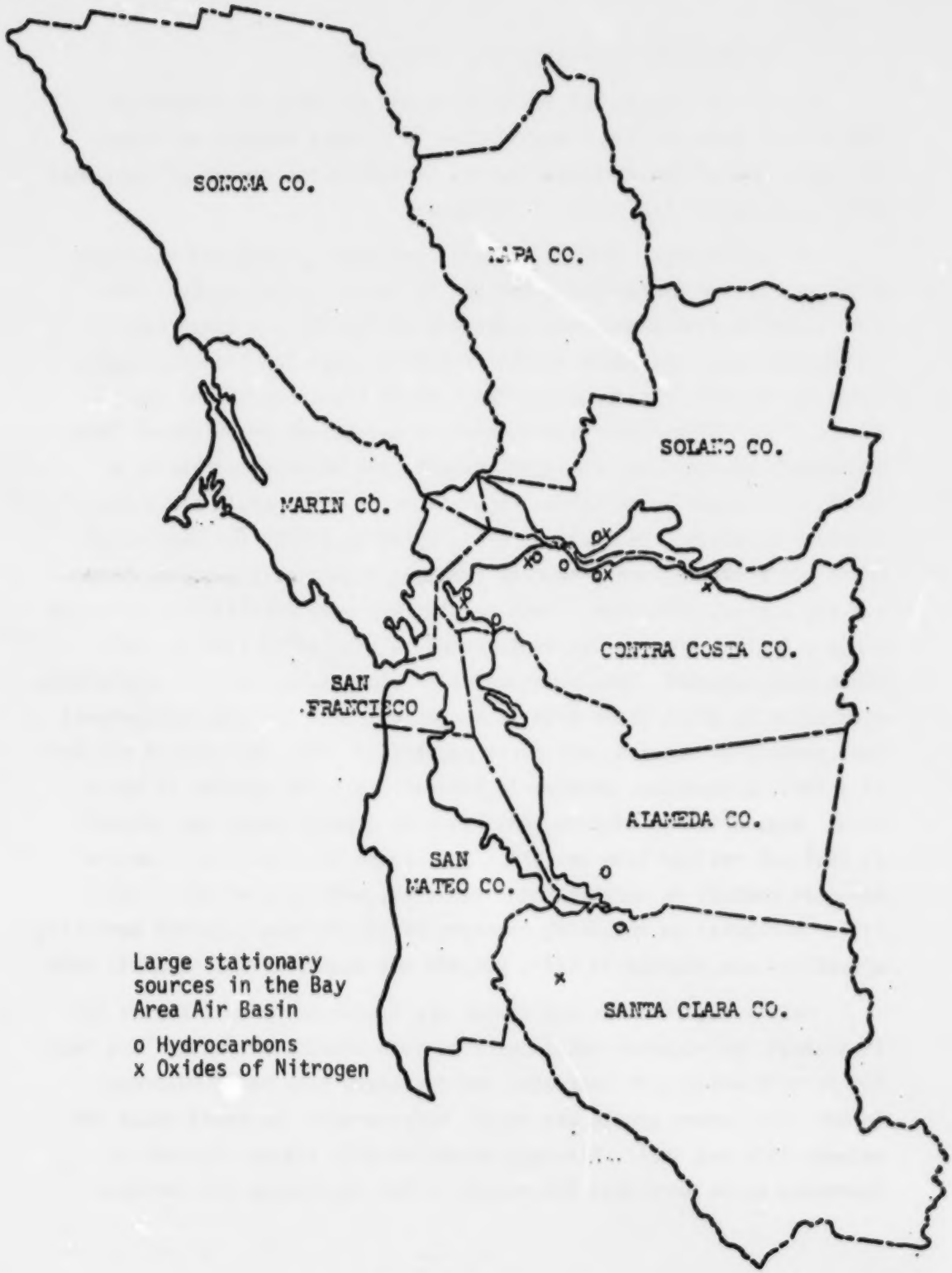

Figure II-5. LARGE STATIONARY SOURCES, BAY AREA AIR BASIN

amounted to 35% in 1973 and dropped to a 26% increase in 1974. The opening of the Bay Area Rapid Transit system during the period had little or no effect on traffic volumes.

C. REDDING (SACRAMENTO VALLEY AIR BASIN)

1. Physical Description

The Sacramento Valley Air Basin, covering an area of nearly 36,000 sq. km. (14,000 sq. miles), includes eight entire counties and portions of two more, viz., Shasta and Solano. The City of Redding is the largest city in Shasta County and lies at the extreme northern end of the Sacramento Valley at an elevation of 190m (580 feet). The air basin takes in the northern third of the great Central Valley as well as parts of the surrounding mountain ranges; its location relative to other California Air Basins is shown in in Figure II-1.

The valley floor slopes up gradually from Sacramento northward to Redding, a distance of about 300 km (190 miles), averaging about 80 km in width. Wind patterns reflect the channeling effect of the mountain ranges on three sides of the air basin. In summer, marine air from San Francisco Bay enters the Sacramento Valley through the Carquinez Straits and the Cordelia Gap in the Coast Range, at the southeastern corner of the air basin. Because of intense heating of the valley floor and the usual presence of a well-developed high pressure cell off the California coast, marine air pushes far up the valley and often reaches the extreme northern end at Redding. In October and November, however, reduced surface heating shuts off the influx of marine air and the prevailing up-valley winds give way to diurnal down-valley flow.

Inversions occur with great frequency in all seasons at Red Bluff, about 50 km south of Redding, which is the nearest location where vertical soundings have been made regularly. From soundings taken at about 0500 PST daily, it appears that there is a surface

inversion on about five days of every six, and less than 3 percent of the soundings show no inversion at all. The atmosphere is especially stable in early fall, predisposing the entire valley to stagnation conditions. In summer, however, the marine inversions are generally accompanied by brisk afternoon winds which provide good ventilation.

2. Air Monitoring

The monitoring station established in Redding by the California Air Resources Board became operational in June, 1970. SAROAD information is as follows:

Address: 1348 Market Street
UTM Northing: 4492770
Easting: 551650
Station Type: Center City - Commercial
Elevation: Above Ground 30' above MSL 612'

The address is in the main city center. Monitoring was discontinued in July, 1975.

3. Population and Growth Factors

The population within the area covered by the Sacramento Valley Air Basin was, in 1972, 1.3 million, of whom about 6 percent (80,000) resided in Shasta County, including less than 2 percent (18,000) in Redding. During the period 1970 to 1974, County population increased at about 2.5 percent per year. It is believed that the population of Redding, however, grew less rapidly, perhaps at about 1 percent per year. Building permits issued by the city between 1971 and 1974 varied from a little more than 200 to a little less than 300 annually.

4. Industry and Other Emitting Activities

All industry in Shasta County is basically oriented to the production of lumber and other wood products. There was no indication of any substantial changes in this production during the period under study, although one plywood plant was subsequently destroyed by fire (March, 1976).

Automobile traffic in Redding increased more rapidly than did population, presumably facilitated by the opening of new freeway links in 1970 and in 1974.

D. STOCKTON AND MODESTO (SAN JOAQUIN VALLEY AIR BASIN)

1. Physical Description

The San Joaquin Valley Air Basin covers the southern part of California's great Central Valley, including seven entire counties and the major part of an eighth. Its area is nearly 65,000 sq. km. (25,000 sq. miles), its length nearly 500 km., along a northwest-southeast orientation. Stockton and Modesto are the largest cities in the two northern-most counties, respectively San Joaquin and Stanislaus. They lie on the San Joaquin River at distances of approximately 30 and 80 km. from its confluence with the Sacramento with the Sacramento River in the delta region. Its northern boundary also marks a meteorological separation from the Sacramento Valley. (See Figure II-1).

In summer marine air enters the valley, primarily through the gap at San Francisco Bay. During the late fall and the winter, cold air draining from mountain slopes flows northward in the San Joaquin Valley and southward in the Sacramento Valley, creating a zone of convergence that fluctuates to the north and south of the delta area. The general circulation, characterized by summertime up-valley and wintertime down-valley winds, permits the transport of pollution over long distances along the axis of the valley. Stockton and Modesto, however, are relatively near the source of the marine air, the low-level gap comprising the delta lowlands and the Carquinez Strait. Modesto, being the more southerly of the two cities, also presumably receives more air from the southern end of the San Francisco Bay Area via the Hayward gap and the Livermore Valley.

2. Air Monitoring

SAROAD information for the monitoring stations at Stockton and Modesto is as follows:

a. Stockton (ST)

Address: 1601 E. Hazleton-sample period: 1/70-12/74
Northing: 4201560
Easting: 676608
Station Type: Center city - Commercial
Elevation: Above ground 88' above MSL 175'

b. Modesto (MO)

Address: 1024 J St. - sample period: 6/70-12/74
UTM Northing: 4167650
Easting: 676608
Station Type: Center City - Commercial
Elevation: Above ground 88' above MSL 175'

The Stockton site is appreciably removed from the city center, while the Modesto site is downtown, close to the city center. These stations were placed in operation late in 1970, so that the data available cover only four full years of the study period, 1970 to 1974.

3. Population and Growth Factors

Population of the area included in the San Joaquin Air Basin was estimated to be about 1.6 million in 1970; this, however, included four counties with a total population of about 54,000 which were subsequently assigned to a different air basin. The rate of growth of population in this twelve-county area following 1970 was about 2 percent per year.

The primary centers of population in the San Joaquin Valley are, in order of decreasing size, Fresno (Fresno County), Stockton (San Joaquin County), Bakersfield (Kern County) and Modesto (Stanislaus County). (Fresno is about 200 km. southeast of Modesto, while Bakersfield is nearly 400 km in the same direction). Population in San Joaquin County, about 300,000 in 1974, increased by less than one percent annually during the study period (1970-1974), with about half the increase occurring in Stockton, where about forty percent of the

population now lives. Population in Stanislaus County, about 200,000 in 1972, increased somewhat more rapidly -- about 1.6 percent annually, with most of the increase occurring in Modesto. Collectively, about half a million people, thirty percent of those in San Joaquin Valley, live in these two counties.

4. Industry and Other Emitting Activities

Agriculture and associated businesses are the dominant industry in the entire San Joaquin Valley Air Basin. Other major sources of basic income in the air basin are mineral extraction, forestry, and various manufacturing industries. In San Joaquin County there is some chemical industry and one power plant; in Stanislaus County, a large fiberboard plant.

Air pollution control regulations for this two-county area are of relatively recent origin. In late 1969, open burning and the use of single-chamber incinerators were banned. Late in 1971, burning of agricultural wastes was restricted to favorable days only. In 1972, new rules were promulgated to govern the use of solvents and architectural coatings. In 1973 a system requiring permits for construction and operation of newsources was undertaken; in 1974 a new rule banned unacceptable orchard heaters. Enforcement of these regulations received no attention until late in 1974, when personnel were assigned to that duty. Emissions from the fiberboard plant apparently began to decrease at about the same time.

Motor vehicle traffic appears to have remained steady in Stanislaus County throughout the five-year period. In San Joaquin County, on the other hand, a new freeway link was opened in 1972, causing an increase in traffic and associated emissions.

E. SALINAS (NORTH CENTRAL COAST AIR BASIN)

1. Physical Description

The North Central Coast Air Basin comprises three California counties, Santa Cruz, Monterey and San Benito; its topography is indicated in Figure II-6. The Salinas Valley is a steep-sloped coastal valley which opens out on Monterey Plain and extends southeastward from the bay with mountain ranges of two to three thousand feet on either side. Salinas lies on the Salinas River, about 20 km. southeast of its mouth at Monterey Bay.

The climate at Salinas is typically coastal. During the summer months, stratus and fog occur frequently, primarily at night and early morning, breaking up under insolation in late morning or early afternoon. In late summer, persistence of the fog and stratus lessens. During the warm season there is a general onshore flow of air; the velocity of the seabreeze is minimal around sunrise, and increases during the day, reaching a maximum in the afternoon. The marine air is heated as it moves inland in the Salinas Valley with a temperature increase of nearly 10 degrees C in the average maximum surface temperature between Salinas and King City. Mean morning mixing heights, i.e., the approximate height of the inversion base, varied from 341 meters in the winter to 529 meters in the summer, according to aircraft soundings carried out for the California Air Resources Board in the period, October 1971 to April 1974.

GENERALIZED TOPOGRAPHY

NORTH CENTRAL COAST AIR BASIN

1. SAN BENITO VALLEY
2. SANTA CLARA VALLEY
3. SALINAS VALLEY
4. MONTEREY BAY
5. CARMEL VALLEY

Figure II-6

2. Air Monitoring

SAROAD information regarding the Salinas air monitoring site is as follows:

Address: 312 E. Alisal St. - sample period: 1/70-12/74
UTM Northing: 4059400
Easting: 621230
Station type: Suburban - Commercial
Elevation: Above ground 31' above MSL 76'

3. Population and Growth Factors

The population of Monterey County increased from 248,000 in 1970 to about 267,000 in 1975, an annual rate of about 1.4 percent. The city of Salinas, with about one fourth of the county's population, was apparently receiving more than four-fifths of the new growth between 1974 and 1975.

4. Industry and Other Emitting Activities

Industry in the North Central Coast Air Basin is primarily related to agriculture, though a power plant and a producing petroleum field are in operation. In the immediate vicinity of Salinas, the principal industry is food processing. To the northeast at Moss Landing on Monterey Bay, are canneries and power generation; farther up the Salinas Valley at San Ardo is the only major stationary source of hydrocarbons in the air basin, the San Ardo oil field, where steam injection enhances oil recovery.

Until 1971, there were no regulations applicable to control of emissions from stationary sources in the air basin. In 1971, rules were passed to prohibit burning waste in outdoor fires or in single-chamber incinerators, to regulate agricultural burning and to limit emissions of oxides of nitrogen from combustion sources. In 1972, limits were placed on discharge of organic vapors from the

use of solvents or architectural coatings and acceptable types of orchard heaters were required. In 1973 a permit system for construction and operation of new facilities was instituted. In 1974, a new air pollution control agency was created, the Monterey Bay Unified Air Pollution Control District, having authority in all three counties, and having (for the first time) a staff of enforcement officers.

Motor vehicle traffic in the air basin was light, increasing only slowly during the five-year study period.

F. LANCASTER (SOUTHEAST DESERT AIR BASIN)

1. Physical Description

The Southeast Desert Air Basin includes the hottest and driest portions of California. It comprises Imperial County, eastern portions of San Bernardino, Riverside, Kern and San Diego Counties, and the northeastern corner of Los Angeles County, including the city of Palmdale and the unincorporated community of Lancaster. Its entire area is about 88,000 sq. km., of which about 4 percent is in Los Angeles County. This portion is in the extreme western end of the Mojave Desert which constitutes the northern part of the air basin. It is sheltered from maritime influences and gross inter-basin transport of polluted air by mountain barriers to the north and south, which join to the west. Limited transport of air from the South Coast Air Basin and from the San Joaquin Valley Air Basin may follow passes in these ranges -- respectively, Soledad Canyon and Tehachapi Pass.

During the summer, when the Pacific High (a semi-permanent cell of high atmospheric pressure) is well developed to the west of California, a thermal trough overlies the desert. The dry, clear conditions result in intense solar radiation, which is highly conducive to photochemical smog formation. Prevailing winds are predominantly from the south and west, so the Lancaster area is relatively little affected by air from the other parts of the air basin and has a greater frequency of calm conditions than some other desert population centers, viz., Victorville and El Centro.

Subsidence inversions over the southeast desert area are usually quite high, at least 2,000 meters above the desert floor, providing little hindrance to vertical dispersion of pollutants. Radiation inversions are prevalent at night throughout the year. In the summer they are usually destroyed early in the day, but in winter they sometimes persist well into the day, limiting mixing to a layer which may be as low as 100 meters.

2. Air Monitoring

SAROAD information for the Lancaster air monitoring station is as follows:

Address: 45547 North Beech St. - sample period 11/70-12/74
UTM Northing: 3841540
Easting: 396540
Station type: Center City - Commercial
Elevation: Above ground 18' above MSL 2347'

The site is characterized as a "center city" location; it lies within a rather diffuse community, as the street number, 45547, may suggest.

3. Population and Growth Factors

An unincorporated area of about 110 sq. km., Lancaster increased in population from about 41,000 in 1972 to 44,000 in 1974, an annual rate of nearly 4 percent. The nearby city of Palmdale, with population approaching 10,000, experienced a similar growth rate. A few other communities in the Los Angeles County portion of the air basin are much smaller than these.

4. Industry and Other Emitting Activities

Lancaster is a desert community with some agriculture and virtually no other industry. Two large asphalt plants are located 22 km. to the southeast, at Littlerock. A large Air Force base, Edwards, is located nearby to the northeast, with headquarters about 30 km. from Lancaster.

In spite of the increase of population noted above, motor vehicle traffic in the Lancaster area is reported to have decreased during the study period (1970 to 1974).

Since Lancaster is in Los Angeles County, it has for many years been subject to the relatively strict air pollution control regulations

which have been enforced in the heavily populated and industrialized sections of the county. No unusual variations in either stationary or mobile sources are known to have occurred during the study period. In 1971, there were changes in the regulations regarding solvents being made subject to control. Other rule changes affected emissions of sulfur oxides, particulates and carbon monoxide, but not hydrocarbons or oxides of nitrogen. New regulations on gasoline storage were announced in 1973, but not made effective until 1975.

G. DENVER, COLORADO

1. Physical Description

The City and County of Denver is part of the Metropolitan Denver Air Quality Control Region, which comprises Denver and seven surrounding counties as shown in Figure II-7. This AQCR roughly coincides with the drainage basin of the South Platte River; it extends from the Continental Divide eastward to the Colorado plains, covering about 20,000 sq. km., with Denver approximately in its center.

Denver is the highest major metropolitan area in the United States, with altitude about 1600 meters. It therefore receives, in clear weather, more ultraviolet irradiation from the sun than cities near sea level. This relatively intense radiation tends to accelerate the photochemical reactions which generate oxidants in urban atmospheres; consequently, Denver may be more subject to oxidant smog than other cities at a similar latitude.

During late fall, the Denver area is subject to frequent atmospheric inversions which prevent dispersion of pollutants and cause the formation of a "brown cloud," with restricted visibility. This phenomenon has been the subject of at least two special investigations[6], primarily because of its noticeability. The topography and meteorology of the area tend to concentrate the urban plume over a well-defined area where it is in sharp visual contrast to surrounding clean air. These conditions are, apparently, not prevalent in the summer months when photochemical oxidant is most often a problem, and when westerly winds are prevalent.

2. Air Monitoring

SAROAD information regarding the CAMP air monitoring station in Denver is as follows.

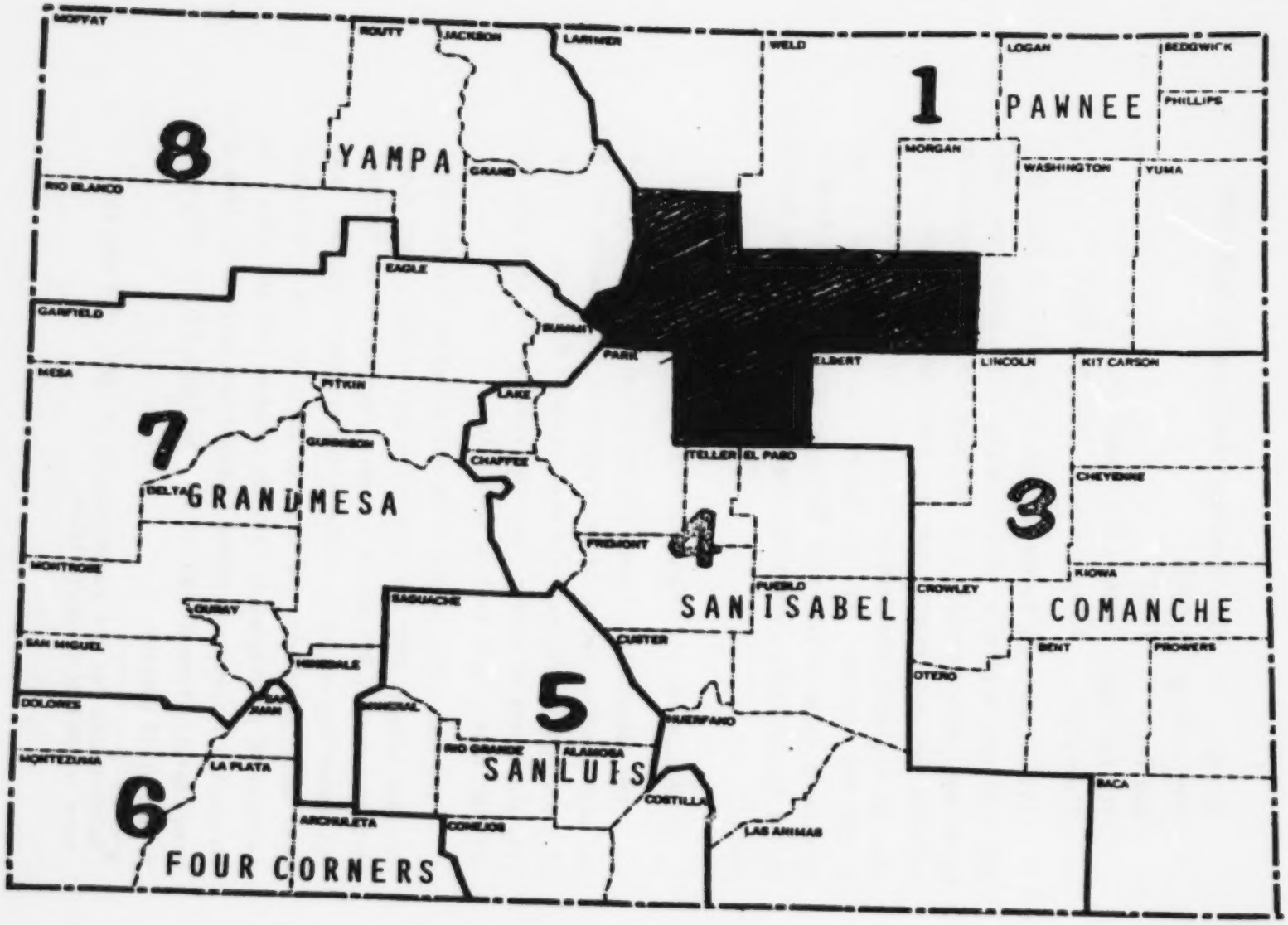

Figure II-7. **COLORADO AIR QUALITY CONTROL REGIONS**
(REGION 2 SHADED)

Address: 2105 Broadway--sample period 1/68-12/73
UTM Northing: 4399920
Easting: 501100
Station Type: Center City--Commercial
Elevation: Above ground 9' above MSL 5220'

This is the only Denver station for which five years oxidant data were available for this study.* Five additional stations have, more recently, been equipped for oxidant monitoring, and data for 1974 indicate that the NAAQS level for ozone, 0.08 ppm, was exceeded more frequently at four of these stations than at the CAMP station. For this reason, the CAMP station is now considered[7] to be "a very poor indicator of the ozone situation in the Denver AQCR, underestimating the problem for the suburban areas."

3. Population and Growth Factors

The Metropolitan Denver Air Pollution Control Region is the most populous region of Colorado, with a population in 1970 of 1,050,000, nearly half the population of Colorado. In the City and County of Denver, the population in the same year was 515,000, nearly half that of the region.

The population of Denver is quite stable, the estimated increase between 1970 and 1974 being only slightly more than 1 percent, about 6,000 people. However, growth in the Metropolitan Denver Region, which includes the suburban counties, has been rapid, continuing the trend established with a 26 percent increase of population in Colorado between 1960 and 1970. The population in Denver Standard Metropolitan Statistical Area also grew rapidly, from 929,000 in 1960 to 1,228,000 in 1970, an increase of 32 percent.

*Oxidant data for the summer months of 1969, 1971 and 1974 were incomplete or unavailable.

4. Industry and Other Emitting Activities

The Denver Air Quality Control Region is heavily metropolitan, but not strongly industrial. Stationary sources include three major power plants, two oil refineries and various other large or medium-sized industrial sources, mainly involved in processing foods and extraction and processing of minerals. Motor vehicle traffic appears to have remained fairly steady, as traffic counts taken in 1971 and 1974 near the air quality monitoring stations showed little change.

Attempts to control or reduce hydrocarbon emissions seem to have been focused mainly on mass transportation programs and reduction of vehicle miles travelled, by such means as encouraging formation of car pools for commuters.

H. PHILADELPHIA, PENNSYLVANIA

1. Physical Description

Philadelphia occupies a section of the Atlantic Coastal Plain lying about 100 km inland from the Atlantic Ocean, south of the Delaware River Valley, at the confluence of the Schuylkill River with the Delaware. The western portion of the city rises into the Piedmont plateau and lies about 80 km southeast of the Appalachian Mountains. Elevations within the city range up to about 100 meters. The climate is typical of that of the Atlantic Coastal Plain.

2. Air Monitoring

Information obtained from SAROAD regarding the Philadelphia monitoring station is as follows:

Address:	2031 Race Street--sample period 1/69-12/74
UTM Northing:	4422830
Easting:	485150
Station Type:	Center City--Mobile (near major traffic arteries)
Elevation:	Above ground 11" above MSL 36'

The Race Street station is the only Philadelphia station for which oxidant data have been accumulated for a five-year period, but samples collected at the Air Management Services Laboratory from 1969 through 1972 indicated a much larger incidence of samples exceeding the NAAQS level for oxidant than did the values obtained at the Race Street station. Detailed data for 1974 were not available.

3. Population and Growth Factors

Philadelphia is a city of nearly two million people and the center of a metropolitan area of more than five million, the Delaware Valley Region. In the decade 1960-1970, the

Philadelphia Standard Metropolitan Statistical Area, consisting of five counties in Pennsylvania and three in New Jersey, increased in population by 11 percent, or about 1 percent annually. The rate of increase for the Delaware Valley Region, covering nine counties, for the period 1969 to 1974, seems to be only about half as large. The City of Philadelphia, on the other hand, has been losing population since 1960. There was a net decrease of -2.7 percent (about 50,000 people) in the decade 1960-1970, which appears to be accelerating in the subsequent years--from 1,950,000 in 1969 to 1,875,000 in 1974.

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III. OXIDANT TREND ANALYSIS

A. INTRODUCTION

A complication in the analysis of trends in oxidant air quality arises from the fact that different indices of oxidant air quality may exhibit different trends. In the present study, this has been seen especially in the analysis of data from the Bay Area Air Pollution Control District. Previously, Trijonis et al[1] reported a similar finding, namely, that the frequency of concentrations exceeding high criterion levels (20 to 30 pphm) in the South Coast Air Basin was reduced significantly more in the decade, 1965 to 1974, than the frequency exceeding the federal standard.

In this study, various air quality indices have been compiled and examined for evidence of trends, separately and in combination. The indices which have been systematically examined are:

- 2nd high: the second highest daily high-hour oxidant value observed during a full year of observations at a single monitoring location.
- Average max.: the average of the highest hourly average oxidant values observed on all days during a full year of monitoring at a single location.
- 3rd quarter average max: the average of the highest average oxidant values observed on all days during the months of July, August and September at a single location.
- Frequency >.08: the frequency, in percent of all days monitored, of days with oxidant values exceeding 0.8 ppm (8 pphm; the NAAQS level) during a full year of monitoring at a single location.
- Frequency >.16: the frequency, in percent of all days monitored, of days with oxidant values exceeding 0.16 ppm (16 pphm) during a full year of monitoring at a single location.

Findings of the study in relation to these various indices are discussed in detail in following sections. Relations between the indices themselves, as shown by the data gathered, are discussed in Section G, with summary and conclusions in Section H.

B. SECOND HIGHEST MAXIMUM

Table III-1 shows the value of this index for each monitoring station for each year of the pentad, 1970-74.

Individual values range from 0.06 ppm (San Francisco, 1974) to 0.29 ppm (Livermore, 1970), both extremes occurring in the Bay Area. Only nine of the values fail to exceed the NAAQS value, 0.08 ppm; these values occurred at two Bay Area stations, at Salinas, CA., and at Denver.

Trend directions,* evaluated from these data, are indicated in the final column of Table III-1. Trend magnitudes are not shown, because (with only five years of data) they are not statistically significant. Nevertheless, the fact that the trend was downward for eight of the nine Bay Area stations is significant ($p < .05$) and indicates a downward trend for that district as a whole. The magnitude of this trend, separately evaluated, amounts to about 25 percent over the four-year interval. For the San Joaquin Valley, California, trends are in opposite directions at the two locations; the overall trend, not significant, is a decrease of about 6 percent over the four-year interval.

C. AVERAGE MAXIMUM

Table III-2 shows the value of this index for each monitoring station for each year of the pentad, 1970-1974.

Individual values range from 0.011 ppm (Philadelphia, 1971) to 0.082 ppm (Modesto, 1970, an incomplete record) or 0.072 ppm (Livermore, 1974). Averages for the pentad, also shown in Table III-2, range from 0.015 (Philadelphia) to 0.060 (Modesto) or 0.057 (Livermore).

Trend directions, indicated in the last column of Table III-2, are predominantly positive, although only the Denver trend was significant. For the Bay Area as a whole, separately evaluated, the trend amounts to

*I.e., the sign of the coefficient of correlation, index vs. year (1970 to 1974). For explanation of trend evaluation, see p. III-18.

TABLE III - 1

OXIDANT LEVEL, 2ND HIGH BY YEAR, AND TREND DIRECTION

(Second highest daily maximum hourly average, ppm)

	'70	'71	'72	'73	'74	Trend
Bay Area						
SF	.14	.15	.07	.08	.06	–
RC	.16	.16	.17	.12	.16	–
SJ	.16	.14	.17	.18	.26	+
FR	.27	.24	.29	.18	.21	–
SL	.21	.24	.14	.20	.17	–
OK	.20	.21	.09	.14	.09	–
RI	.18	.14	.10	.10	.08	–
PT	.18	.18	.18	.10	.10	–
LV	.29	.21	.18	.20	.25	–
Sacramento Valley						
Redding	(.13)[a]	.13	.14	.13	.14	(0)[c]
San Joaquin Valley						
Stockton	.17	.14	.13	.18	.15	+
Modesto	(.16)[a]	.22	.16	.17	.16	(–)[c]
No. Central Coast						
Salinas	(.07)[b]	.09	.08	.13	.10	(+)[c]
S. E. Desert						
Lancaster	–	.13	.14	.20	.14	(+)[c]

	'68	'69	'70	'71	'72	'73	'74	Trend
Denver	0.11	0.08	0.08	0.10	0.09	0.08	–	(–)[c]
Philadelphia	–	0.11	0.12	0.13	0.12	0.19	–	(+)[c]
Whiteface Mtn.	Not Received							

a. Only 7 months of monitoring.

b. Only 9 months of monitoring.

c. Parentheses indicate data not complete over the period 1970-1974.

TABLE III - 2

TOTAL OXIDANT AVERAGE MAXIMA AND TREND DIRECTIONS

(Yearly average of daily maximum hourly average, ppm)

	'70	'71	'72	'73	'74	Ave.	Trend
Bay Area							
SF	.028	.017	.022	.018	.026	.022	−
RC	.037	.041	.043	.032	.048	.040	+
SJ	.055	.038	.036	.047	.065	.048	+
FR	.052	.047	.056	.047	.062	.053	+
SL	.049	.042	.032	.048	.059	.046	+
OK	.036	.022	.028	.026	.034	.029	+
RI	.042	.032	.032	.032	.028	.033	−
PT	.052	.042	.046	.036	.044	.044	−
LV	.063	.050	.045	.055	.072	.057	+
Sacramento Valley							
Redding	(.057)[a]	.050	.049	.052	.062	(.054)	(+)[d]
San Joaquin							
Stockton	.059	.035	.036	.056	.056	.048	+
Modesto	(.082)[a]	.061	.048	.050	.062	(.060)	(−)[d]
No. Central Coast							
Salinas	(.036)[b]	.038	.038	.041	.044	(.039)	(+)[d]
S. E. Desert							
Lancaster	.025[c]	.032	.063	.072	.050	(.055)	(+)[d]

	'68	'69	'70	'71	'72	'73	'74	Ave.	Trend
Denver	.032	.028	.023	.022	.022	.013			(−)[d,e]
Philadelphia	−	.018	.014	.012	.011	.015	.021	.015	+
Whiteface Mtn.	Not Received								

a. Only 7 months of monitoring.

b. Only 9 months of monitoring.

c. Only 2 months of monitoring

d. Parentheses indicate data not complete over the period 1970-1974.

e. Significant, $p < 0.01$; trend, - 0.0033 ppm/yr.

an increase of about 4 percent in the four-year interval. For the sixteen stations nationwide, eleven positive trends are indicated, while for the nine stations of the Bay Area, six positive trends are indicated; the proportion is not high enough to be statistically significant in either case. Trends for the two monitoring locations in the San Joaquin Valley are in opposite directions; the over-all trend, not significant, is a decrease of about 12 percent over the four-year interval.

Data for the period 1968 to 1973 for Denver showed a downward trend, significant at the one percent level, of 3.3 ppb (0.0033 ppm) per year. This is more than ten percent of the 1968 level; over the six year period, the total decline amounted to 59 percent. The trend in the annual 2nd high (Table III-1) was in the same direction, but smaller and not significant.

D. THIRD QUARTER AVERAGE MAXIMUM

Table III-3 shows the value of this index for each monitoring station for each year of the pentad, 1970-1974.

Individual values range from 0.010 ppm (Philadelphia, 1972) to 0.11 (Modesto, 1971; Lancaster, 1973; San Jose and Livermore, 1974). Averages for the five summers, also shown in Table III-3, range from 0.013 ppm (Philadelphia, based on incomplete information) or 0.027 ppm (San Francisco) to 0.096 (Modesto).

Trend directions, indicated in Table III-3, are about evenly divided between positive and negative; none of these trends is statistically significant. For the Bay Area as a whole, separately evaluated, the composite trend amounts to a decrease of about ten percent during the four-year interval. For the two monitoring stations in the San Joaquin Valley, trends are in opposite directions; the over-all trend, not significant, is a decrease of about 7 percent over the four-year interval.

TABLE III - 3

OXIDANT 3RD QUARTER AVERAGE MAXIMA AND TREND DIRECTIONS

(Three-month[a] average of daily maximum hourly average, ppm)

	'70	'71	'72	'73	'74	Ave.	Trend
Bay Area							
SF	.050	.023	.027	.013	.023	.027	–
RC	.047	.053	.057	.033	.053	.049	–
SJ	.087	.053	.057	.063	.11	.074	+
FR	.080	.080	.080	.053	.080	.075	–
SL	.057	.057	.050	.050	.066	.056	+
OK	.047	.043	.030	.027	.043	.038	–
RI	.057	.037	.037	.033	.040	.041	–
PT	.077	.070	.073	.043	.050	.063	–
LV	.090	.080	.063	.083	.11	.085	+
Sacramento Valley							
Redding	.083	.087	.077	.083	.097	.085	+
San Joaquin Valley							
Stockton	.083	.032	.060	.083	.087	.069	+
Modesto	.10	.11	.087	.083	.10	.096	–
No. Central Coast							
Salinas	.037	.037	.037	.043	.043	.039	+
S. E. Desert							
Lancaster	NA	NA	.080	.11	.087	(.09)[b]	(+)[b]

	'68	'69	'70	'71	'72	'73	'74	Ave.	Trend
Denver	0.037	NA	0.027	NA	0.033	0.017		(.026)[b]	(–)[b]
Philadelphia		.018	.014	.010	.011	0.018		(.013)[b]	(+)[b]
Whiteface Mtn.	Not Received								

a. Averages for July, August and September

b. Parentheses indicate data not complete for these three months in all five years.

E. FREQUENCY EXCEEDING NAAQS LEVEL

Table III-4 shows the value of this index for each monitoring station for each year of the pentad, 1970-74.

Individual values range from zero (which occurred four times each at San Francisco and Salinas, twice each at Oakland, Richmond and Pittsburg, and once at Lancaster, with only two months of observations) to 22.7 percent (Lancaster, 1973). For the entire pentad, values ranged from 0.3 percent (San Francisco) to about 16 percent (Modesto, 5 months information missing) or 13 percent (Livermore).

Trend directions, as shown, were almost equally divided between positive and negative. None of these trends were statistically significant. For the Bay Area, seven of the nine stations showed negative trends; the composite trend was a reduction of the frequency value by about 25 percent during the four-year interval. For the two stations in the San Joaquin Valley, the trends seemed to be in opposite directions, with net effect near zero.

F. FREQUENCY EXCEEDING TWICE NAAQS LEVEL

Table III-5 shows the value of this index for each monitoring station for each year of the pentad, 1970-74.

It is of interest to note that days in this category were so rare that only a handful of non-zero entries appear. The chosen criterion level, .16 ppm, was exceeded more than once at only four stations (namely, Fremont, Livermore, San Jose, and San Leandro) in the Bay Area, and in Denver.

G. RELATIONS BETWEEN THE INDICES

Tables III-1 to III-5 provided indications that the various indices of air quality may be differently affected by changes in air quality. Table III-6 presents, for ready comparison, the trend direction information from the earlier tables. It appears from this

TABLE III - 4

FREQUENCIES OF EXCEEDING 0.08 ppm, AND TREND DIRECTIONS

(Days with hourly average oxidant levels exceeding 0.08 ppm, shown as percentage of days monitored)

	'70	'71	'72	'73	'74	Ave.	Trend
Bay Area							
SF	1.6	0	0	0	0	0.3	–
RC	3.4	3.7	3.4	2.7	2.7	3.2	–
SJ	11.0	8.7	3.8	8.4	17.1	7.8	+
FR	9.4	9.2	10.0	5.9	6.9	8.3	–
SL	7.3	4.7	3.4	6.7	3.8	5.2	–
OK	3.2	2.2	0	1.8	0	1.4	–
RI	5.6	1.8	0	1.4	0	1.8	–
PT	8.4	4.4	4.4	0	0	3.4	–
LV	16.9	9.2	5.1	14.1	18.9	12.8	+
Sacramento Valley							
Redding	(12.8)[a]	9.0	8.4	11.9	11.9	(≈10)	(+)
San Joaquin							
Stockton	8.4	3.4	2.4	11.9	6.9	6.6	+
Modesto	(27.3)[a]	18.9	11.9	11.9	16.9	(≈16)	(–)
No. Central Coast							
Salinas	(0)[b]	0	0	2.4	0	(0.5)	(+)
S. E. Desert							
Lancaster	(0)[c]	1.7	1.4	22.7	11.9	(≈9)	(+)

	'68	'69	'70	'71	'72	'73	'74	Trend
Denver	14.9	4.7	8.1	5.6	18.2	5.3	–	(+)
Philadelphia[e]		0.5	0.5	0.2	0.3	2.8		(+)
Whiteface Mtn.	Not Received							

a. Only seven months of monitoring.
b. Only nine months of monitoring.
c. Only two months of monitoring.
d. Parentheses indicate data not complete over the period 1970-1974.
e. Data for Philadelphia are given in terms of percent of all hours during which the criterion level is exceeded. The frequency in terms of days on which such levels were reached may be much higher.

TABLE III - 5

FREQUENCIES OF EXCEEDING 0.16 ppm HOURLY AVERAGE OXIDANT

(Days with hourly average oxidant levels exceeding 0.16 ppm, shown as percentage of days monitored)

	'69	'70	'71	'72	'73	'74
Bay Area						
SF		0	0	0	0	0
RC		0	0.3	0	0	0
SJ		0	0	0	0.3	1.8
FR		1.8	1.5	1.6	0	0
SL		0.3	0.3	0	1.0	0
OK		0	0.6	0	0	0
RI		0	0.3	0	0	0
PT		0	0	0	0	0
LV		1.3	0	0	0	1.7
Sacramento Valley						
Redding		0	0	0	0	0
San Joaquin						
Stockton		0	0	0	0	0
Modesto		0	0	0	0	0
North Central Coast						
Salinas		0	0	0	0	0
S. E. Desert						
Lancaster		0	0	0	0	0
Denver	0	0	0.5	0.3	0.4	
Philadelphia	0.0	0.0	0.0	0.0	0.0	
Whiteface Mountain		Not Received				

TABLE III - 6

TREND DIRECTIONS FOR VARIOUS OXIDANT INDICES,
AS SHOWN AT VARIOUS MONITORING STATIONS

	SF	RC	SJ	FR	SL	OK	RI	PT	LV	RD	ST	MO	SA	LN	DV	PH
Second-high	–	–	+	–	–	–	–	–	–	0	+	–	+	+	–	+
Average Max.	–	+	+	+	+	+	–	–	+	+	+	–	+	+	–	+
3rd Qtr. Ave. Max.	–	–	+	–	+	–	–	–	+	+	+	–	+	+	–	+
Frequency > 0.08	–	–	+	–	–	–	–	–	+	+	+	–	+	+	+	–

presentation that there must be a substantial degree of independence between the second-high statistic and the yearly average maximum, since there are 5 disagreements among sixteen comparisons for these indices. Perhaps more important, the second-high statistic shows a statistically significant trend for the Bay Area (when evaluated for the nine stations selected for this study), while the remaining statistics do not.

To explore these relations, several auxiliary analyses were undertaken. First, correlation coefficients were computed, using paired values of different indices for individual stations year by year, and for all five years. Second, coefficients of concordance were computed for 12 California stations as ranked according to different indices in various combinations. Third, a two-way analysis of variance was performed to determine whether the error variance associated with the use of the second-high index was consistent with statistically sound use of this index in the detection of trends in the present study. Results of these analyses are discussed in the three following subsections:

a. Correlation between Oxidant Indices

Using data from the nine Bay Area stations, the 2nd-high statistic and the yearly average maximum were compared at 45 data points (five years for each station), yielding a correlation coefficient of 0.728. As anticipated, this correlation is far from perfect, although it is, indeed, statistically convincing. When the average maximum is taken as an independent variable, the regression coefficient is 3.3* and a standard error of estimate is 0.031 ppm, corresponding to a rather large coefficient of variation, about twenty percent. Thus, it is reasonable to conclude that the 2nd-high statistic may have, in relation to oxidant data analysis, advantages that will bear further investigation.

Correlation coefficients between these two indices for the individual years showed very wide variation; values for successive years starting in 1970

*This means that a unit increase in the average maximum leads to an expected increase of 3.3 units in the 2nd-high value.

were .67, .42, .95, .88, and .96 respectively. Combining the three later years yielded a coefficient of 0.866, indicating much less independence between these indices. Since this coefficient, also, is highly significant, the finding suggests that physical factors which cannot be detected by this analysis may have caused the change.

Since the correlation between 2nd-high and annual average maximum indices was especially low for 1971, it was of interest to determine whether the 3rd-quarter average maximum would provide a better correlation. This might be expected, in view of the fact that there is a higher frequency of high-oxidant days in summer than in other seasons, especially on the West Coast. A test of this correlation (i.e., 2nd-high and 3rd quarter ave. max.) for 1971 yielded a coefficient of 0.61; higher than the figure (0.42) for the yearly average maximum, but still lower than the other coefficients cited in the previous paragraph.

b. Concordance between Oxidant Indices

If different oxidant indices reflect different, incompletely correlated, aspects of air quality, it should, perhaps, be expected that a set of monitoring stations would rank differently when ranked in terms of different indices. This hypothesis was tested by ranking twelve northern California stations (nine Bay Area stations plus Redding, Stockton and Modesto) by four indices (2nd-high oxidant, yearly average maximum, third quarter average maximum and frequency equal to or exceeding 0.08 ppm), then computing coefficients of concordance.[2] (This coefficient measures the extent of agreement among several sets of ranks, ranging from zero for no agreement to unity for full agreement.) When the set of four indices was used to rank the twelve stations according to five-year average values, the coefficient of concordance was 0.83. When the 2nd-high statistic was excluded and the remaining three indices used, the coefficient was 0.99. (Both significant at 1% level.)

The rankings obtained in this procedure are shown in Table III-7. Examination of this table suggested that the main differences between the

TABLE III - 7

RANKINGS OF 12 CALIFORNIA MONITORING STATIONS
ACCORDING TO VARIOUS OXIDANT AIR QUALITY INDICES

Index (5 yr. ave.)	FR	LV	SL	SJ	MO	ST	PT	RC	OK	RD	RI	SF
Second-high	1	2	3	4	5	6	7	8	9	10	11	12
Yearly Ave. Max.	4	2	7	6	1	5	8	9	11	3	10	12
3rd Qtr. Ave. Max.	4	2½	8	5	1	6	7	9	11	2½	10	12
Frequency ≥.08	4	2	7	5	1	6	8	9	11	3	10	12
Frequency ≥.16	1	2	4	3								

ranking for the 2nd-high index and the other three could be due to differences at four stations: Fremont, San Leandro, Modesto and Redding. In fact, when the procedure was repeated with these four stations deleted, the coefficient of concordance for all four indices was 0.98.

The results confirm that very good agreement between these indices can be obtained under restricted circumstances and with carefully selected monitoring sites. More divergence may be expected, however, when observations are collected from monitoring stations representing different types of terrain or a greater variety of urban and suburban or rural sites.

c. Analysis of Variance, Second-High Statistic

To test the significance of yearly changes and differences between stations, in view of the expected rather large variance of the extreme-value statistic called 2nd-high, an analysis of variance was performed, using data for 9 stations of the Bay Area monitoring network. Results are presented in Table III-8.

Year averages ranged from 0.144 to 0.199 ppm, and the yearly change effect was significant at the 5 percent level. Station averages ranged from 0.100 to 0.238 ppm and the differences between stations were significant at the 1 percent level. Residual variance was 0.00144 ppm ^{2}, corresponding to an error standard deviation of 0.038 ppm -- large, but clearly not disabling for data bases as large as the one treated here.

H. REVIEW AND CONCLUSIONS

Oxidant air quality data from five air quality control regions in California and from Denver, Colorado, and Philadelphia, Pennsylvania, have been tabulated and their trends evaluated over the five-year period 1970 to 1974. Various air quality indices have been applied in this analysis, namely:

TABLE III - 8

ANALYSIS OF VARIANCE OF SECOND-HIGH OXIDANT LEVELS[a]
FOR 9 BAY AREA MONITORING STATIONS, FIVE YEARS (1970-1974)

Station	Year					Total	Average
	70	71	72	73	74		
SF	14	15	7	8	6	50	10.0
RC	16	16	17	12	16	77	15.4
SJ	16	14	17	18	26	91	18.2
FR	27	24	29	18	21	119	23.8
SL	21	24	14	20	17	96	19.2
OK	20	21	9	14	9	73	14.6
RI	18	14	10	10	8	60	12.0
PT	18	18	18	10	10	74	14.8
LV	29	21	18	20	25	113	22.6
Total	179	167	139	130	138	753	
Average	19.9	18.6	15.4	14.4	15.3		16.7

Source of Variance	Sum of Squared Deviations	Degrees of Freedom	Variance Estimate	F Ratio	p
Years	199	4	50	3.5	< 5%
Stations	852	8	107	7.4	< 1%
Residual	460	32	14.4		
Total	1511	44	34		

a. Values coded, for convenience, as pphm.

- The second highest daily high-hour oxidant level in each calendar year;
- The yearly average daily high-hour oxidant level;
- The average daily high-hour oxidant for three summer months (July, August, September) of each year;
- The percentage frequency of days with high-hour average exceeding the NAAQS (0.08 ppm).

The percentage frequency of days with high-hour averages exceeding 0.16 ppm was also tabulated, but the number of non-zero values was too small for useful statistical comparisons.

With a single exception, the data for 1970 to 1974 which were compiled (Tables III-1 to III-5) revealed no trends which were statistically significant at the five percent level. The exception was the significant decrease in oxidant levels in the Bay Area, when expressed in terms of the second highest hourly average and utilizing the pooled information from 9 Bay Area monitoring stations. This trend amounts to a decrease of about 25 percent over the four-year interval from 1970 to 1974, giving an average of about 6 percent per year for that period.

Data for the period 1968 to 1973 for Denver, in terms of yearly average high-hour oxidant, also showed a significant downward trend, amounting to more than ten percent per year. This trend was not reflected in the statistics for frequency of violations of the ambient air standard during the same years.

Various analyses were performed to explore the indicated relations between the air quality indices described above. By several tests, it appears that the other indices follow the second-high statistic in a general way, but not closely.

An analysis of variance of the five years' data from the Bay Area confirms that both the observed yearly trend and the observed

differences in air quality at various monitoring stations are statistically significant and, therefore, not attributable to random variations in oxidant measurements or to unsystematic variations in external factors which may cause short-term fluctuations in oxidant levels. In short, these effects are too large to be accounted for by accidental variations; they therefore require explanation in terms of the major variables intrinsic to the determination of air quality: emissions and weather.

REFERENCES AND NOTES

1. Trijonis, Peng, McRae and Lees, "Emissions and Air Quality Trends in the South Coast Air Basin," EQL Memorandum No. 16 (January 1976). Calif. Inst. of Technology, Pasadena, Ca.

2. Kendall, M.G., "Rank Correlation Methods." Griffin, London, 1948.

The linear trend is evaluated as the coefficient of regression, where the air quality index is taken as the dependent variable and the independent variable is the year. The trend is statistically significant at a level p if the correlation between the two variables is significant at that level. Using the conventional significance level, $p = 0.05$, trends calculated for a 5-year data base are significant only if the coefficient of correlation equals or exceeds 0.88 in absolute value, independent of sign.

The trend parameter is the coefficient of regression, which has units of parts per million per year.

The coefficient of concordance is defined as

$$W = 12S/[m^2(n^3-n)],$$

where m is the number of indices to be compared, n is the number of items to be ranked, and S is the sum of the squares of the deviations of the n rank totals from their mean, which is given by $m(n+1)/2$.

The significance of the coefficient of concordance can be tested by the use of the F-distribution, calculating F as $(m-1)W/(1-W)$ and entering the F tables with $n-1-2/m$ degrees of freedom for the greater estimate and $(m-1)(n-1-2/m)$ degrees of freedom for the lesser estimate. As an example, if $m = 4$ and $n = 12$, then W is significant at the 5 percent level if it equals or exceeds 0.42.

IV. OXIDANT:PRECURSOR RELATIONSHIPS

A. SOUTH COAST AIR BASIN, CALIFORNIA

The South Coast Air Basin, which includes the County of Los Angeles and all or part of five surrounding counties, was not selected for study as part of this project. The omission was occasioned not by lack of appropriate information but by the recent publication of a report, "Emissions and Air Quality Trends in the South Coast Air Basin," which substantially achieved the objectives of the PES project, insofar as the South Coast Air Basin might be concerned. Since the scope of that report--EQL Memorandum No. 16, by John C. Trijonis, Ted K. Peng, Gregory J. McRae and Lester Lees, January 1976--was directly comparable with the work reported here, it is felt appropriate to cite its findings here for the convenience of interested readers.

The paper documents the historical trends of pollutant emissions and ambient air quality for the period 1965-1974. Emission trends are developed for nitrogen oxides and reactive hydrocarbons, as well as carbon monoxide. Ambient air concentrations of total oxides of nitrogen, nitrogen dioxide, oxidant and carbon monoxide are reviewed and compared to the changes in emissions, and various air quality indices are presented for each pollutant.

With respect to the oxidant air quality, the authors report a Basin-wide improvement of 19 percent over the decade, as the average improvement for a network of thirteen stations. The estimate of Basin-wide reductions in emissions of reactive hydrocarbons, 18 percent, agrees well with this oxidant reduction. The geographical trends in oxidant agree, qualitatively, with the geographical trends in reactive hydrocarbon emissions, especially for Los Angeles County. The oxidant air quality improved much

more in the western areas than in the downwind eastern parts of the Basin, leading to the postulate that an increase in oxides of nitrogen emissions improved oxidant air quality near "source-intensive" areas, but caused deterioration in areas farther downwind.

Histograms of the number of hours that oxidant concentrations exceeded various levels show a much greater improvement in dosages at high levels (20 to 30 pphm) than in dosages at low levels, 8 pphm. Thus, it appears that present control strategies have been more effective in reducing the higher ambient oxidant concentrations than the lower. This finding may have implications regarding the feasibility of achieving the NAAQS level in the South Coast Air Basin.

B. REVIEW OF EMISSIONS AND TRENDS, 1970-1974

1. Bay Area Air Pollution Control District

Emission inventory estimates for the Bay Area Air Pollution Control District were reviewed in APCD bulletins dated late 1975 and early 1976. Estimates for the years 1970 to 1974, for hydrocarbons and oxides of nitrogen, are shown in Table IV-1.

The estimates indicate that, during the five year period, hydrocarbon emissions declined, although not steadily. Evaluated by a least squares fit, the series shows a trend of -27 tons per day per year, or about 2.5 percent decline per year. During the same interval, oxides of nitrogen emissions increased, then decreased during the last year, arriving at a level perhaps 3 percent lower than the 1970 estimate. Mobile sources accounted for a little more than half the hydrocarbon emissions and a little less than two thirds of the oxides of nitrogen, decreasing slightly for both, over the four year interval. The ratio of hydrocarbon emissions to oxides of nitrogen emissions seems to have decreased by at least ten percent.

These emissions are, of course, distributed unevenly with respect to both geographic subdivisions and source-type categories. Hydrocarbon emissions estimated by county for 1974 are shown in Table IV-2, together with the estimated totals for stationary and mobile sources and the ratio, stationary/mobile. The total ranges from 18 tons per day, for Napa County, to 241 tons per day, for Santa Clara County. The contribution of stationary sources is greatest in Contra Costs County, where there are a series of large industrial sources along an extensive shoreline. The contribution of mobile sources is greatest in Santa Clara County, which has experienced rapid population growth during the past decade; relative to the stationary sources, however, the contribution of mobile sources is greatest in Marin County, a mountainous suburban county having little industry.

TABLE IV-1

POLLUTANT EMISSIONS BY YEAR, BAY AREA AIR POLLUTION CONTROL DISTRICT[a]

	tons per day				
	1970	1971	1972	1973	1974
Hydrocarbons, Total	1140	1113	1135	1069	1028
Stationary sources	510	510	550	510	510
Mobile sources	630	603	585	559	518
Percent mobile sources	55	53	51	52	51
Oxides of Nitrogen, Total	740	740	790	820	720
Stationary sources	277	267	296	315	276
Mobile sources	463	473	494	505	444
Percent mobile sources	63	64	63	62	62
Ratio, HC(Total)/NO_x(Total)	1.54	1.50	1.44	1.30	1.43

[a] Source: "Emissions Trends Report, Base Year 1974", Bay Area Air Pollution Control District, February 6, 1976.

TABLE IV-2

BAY AREA AIR POLLUTION CONTROL DISTRICT HYDROCARBON EMISSIONS BY COUNTY, 1974

(tons per day)

County	Total	Stationary	Mobile	Ratio
San Francisco	108	54	54	1.0
San Mateo	111	51	60	0.9
Santa Clara	241	109	131	0.8
Alameda	226	103	123	0.8
Contra Costa	172	118	55	2.2
Solano	53	23	30	0.8
Napa	18	9	9	1.0
Sonoma	55	20	35	0.7
Marin	45	16	29	0.6
Total	1,028	504	524	1.0

Similar information regarding emissions of oxides of nitrogen is presented in Table IV-3. Here the total emissions range from 10 tons per day (in Napa Co.) to 172 tons per day (in Contra Costa). Emissions from stationary sources range from only 1 ton per day to 121; from mobile sources, from 9 to 124. Contra Costa county has, by far, the highest ratio of stationary source emissions to mobile source emissions, for oxides of nitrogen as for hydrocarbons. It is of interest to note, however, that Contra Costa County has the lowest ratio of hydrocarbon emissions to oxides of nitrogen emissions, namely about 1.0, as compared to ratios up to about 1.6 for other counties.

Trends in mobile-source emissions may be substantially different from trends in stationary-source emissions, since control programs for the two types of sources are substantially independent of each other, both technologically and administratively. To estimate these trends for areas constituting traffic centers, emissions are usualy computed by estimating traffic volume (in terms of vehicle miles travelled) and multiplying by appropriate emission factors. Emission factors have been subject to a downward trend during the last several years because of the replacement of old automobiles with newer vehicles equipped with emission control systems. On the other hand, traffic volumes have increased in many areas, so that the net trend may be an increase in some places, despite vehicle emission controls.

An independent estimate of trends in mobile source emissions was made, using traffic counts for state highways, published annually by the California Department of Transportation. For this purpose it was assumed that trends in highway traffic volumes would be accompanied by similar trends in traffic on local streets. Relative traffic volume for each locality was thus estimated from traffic counts on the most heavily travelled highways -- usually, two roads intersecting in or near the city of interest. These traffic volumes for various years were multiplied by appropriate emission factors, derived by the California Air Resources Board, representing the California vehicle

TABLE IV-3

BAY AREA AIR POLLUTION CONTROL DISTRICT OXIDES OF NITROGEN EMISSIONS BY COUNTY, 1974 (tons per day)

County	Total	Stationary	Mobile	Ratio
San Francisco	64	15	49	0.3
San Mateo	68	6	62	0.1
Santa Clara	156	37	119	0.3
Alameda	144	20	124	0,2
Contra Costa	172	121	51	2,4
Solano	43	14	29	0.5
Napa	10	1	9	0.1
Sonoma	34	1	33	0,03
Marin	31	2	29	0.07
	722	217	505	0.43

inventory and the California vehicle emission standards.[1] These emissions factors were adjusted for an average speed of 45 miles per hour for freeways and 40 mph for limited access highways except that for 1974, when the California speed limit was lowered, 40 mph was assumed for freeways also. The products of traffic counts by emission factors were normalized to a value of 1.00 for the year, 1970; Table IV-4 shows the values thus calculated for various Bay Area localities.

It is of interest to note, from Table IV-4, that the indicated trend in hydrocarbon emissions is downward in each of the older major population centers except San Jose. On the other hand, Fremont, Livermore and San Rafael, outlying communities which like San Jose have recently experienced substantial population growth, like San Jose also experienced growth in hydrocarbon emissions from motor vehicles (although not to the same degree as San Jose).

Emissions of oxides of nitrogen from mobile sources, according to these estimates, increased after 1970 in all the listed locations except Richmond (northwestern Contra Costa County). In most cases they reached a maximum in 1972 or 1973, then underwent a noticeable decline in 1974. The largest increase was registered in San Jose, amounting to 35 percent in 1973, then declining to 26 percent in 1974. Due to the reduction in oxides of nitrogen emissions experienced in 1974, 1974 emissions from mobile sources were lower than 1970 emissions in three localities: San Francisco, Richmond, and Redwood City.

The BAAPCD Emissions Inventory Summary Report for Base Year 1974 lists eighty-four major point sources of various pollutants, where "major" implies emissions of at least 200 pounds per day. The list includes eight facilities estimated to emit at least 5 tons of hydrocarbons per day and six which emit at least five tons of oxides of nitrogen per day. Collectively, these plants emit more than half the oxides of nitrogen attributed to stationary sources

TABLE IV-4

MOBILE SOURCE EMISSION INDICES*

County			1970	1971	1972	1973	1974
San Francisco	San Francisco	Hydrocarbon	1.00	0.97	0.93	0.90	0.87
		NO_x	1.00	1.03	1.04	1.02	0.96
Marin	San Rafael	Hydrocarbon	1.00	0.99	1.01	1.00	1.07
		NO_x	1.00	1.07	1.13	1.16	1.12
Contra Costa	Richmond	Hydrocarbon	1.00	0.91	0.89	0.86	0.86
		NO_x	1.00	0.98	1.00	1.00	0.91
	Pittsburg	Hydrocarbon	1.00	0.95	1.00	0.97	0.98
		NO_x	1.00	1.03	1.12	1.12	1.02
Alameda	Oakland	Hydrocarbon	1.00	1.01	0.99	0.96	0.96
		NO_x	1.00	1.09	1.11	1.11	1.01
	Fremont	Hydrocarbon	1.00	1.03	1.08	1.06	1.06
		NO_x	1.00	1.12	1.21	1.23	1.11
	Livermore	Hydrocarbon	1.00	1.13	1.07	1.07	1.07
		NO_x	1.00	1.22	1.20	1.23	1.11
Santa Clara	San Jose	Hydrocarbon	1.00	1.09	1.15	1.17	1.21
		NO_x	1.00	1.18	1.29	1.35	1.26
San Mateo	Redwood City	Hydrocarbon	1.00	0.93	0.94	0.89	0.89
		NO_x	1.00	1.01	1.05	1.03	0.94

*Normalized to 1970

and about one fifth of the hydrocarbons from stationary sources. Figure II-5 shows the geographical distribution of these large sources: the largest number of them are situated in Contra Costa County, on the shore of one of the bays or connecting straits. Other large facilities exist, as shown, in Solano, Alameda, and Santa Clara Counties. Except for two electric power generating plants in the eastern part of San Francisco, all sources emitting more than one ton per day of either hydrocarbons or oxides of nitrogen are also distributed in a pattern similar to that shown in Figure II-5, although with more smaller emitters along the shore of Alameda County.

The largest emitters of hydrocarbons are petroleum refineries, chemical manufacturing plants, and automobile assembly plants. Principal emitters of oxides of nitrogen include the refineries and chemical plants and, in addition, electric power generating plants and a large cement plant.

2. Redding (Sacramento Valley Air Basin)

Emission inventory information for Shasta County has been obtained from the Shasta Air Pollution Control District and the California Air Resources Board. Table IV-5 shows estimates for the years 1970 to 1974, except 1971, for hydrocarbons and oxides of nitrogen.

The estimates indicate that hydrocarbon emissions, on the whole, decreased by about 45 percent between 1970 and 1974 while oxides of nitrogen emissions decreased by about 20 percent between 1970 and 1972, thereafter undergoing even less variation. For hydrocarbons, the fraction of emissions attributable to motor vehicles and other mobile sources decreased strongly in the period 1970 to 1972, going from 69 percent to 41 percent; subsequent changes in the proportion of the contributions from motor vehicles were relatively inconsequential. For oxides of nitrogen, the proportion attributable to mobile sources remained at seventy to eighty percent.

TABLE IV-5

POLLUTANT EMISSIONS BY YEAR, SHASTA COUNTY PORTION OF SACRAMENTO VALLEY AIR BASIN

	tons per day			
	1970[a]	1972[b]	1973[b]	1974[c]
Hydrocarbons, Total	45	39	28	25
Stationary sources	15	22	17	13
Mobile sources	31	16	11	11
Percent mobile sources	69	41	39	44
Oxides of nitrogen, Total	22	17	19	18
Stationary sources	7	3	5	4
Mobile sources	15	14	14	14
Percent mobile sources	69	81	73	77
Ratio, HC(Total)/NO_x(Total)	2.0	2.3	1.5	1.4

a Source: California Air Resources Board

b Source: California Air Resources Board, preliminary data

c Source: Shasta County Emission Inventory 1974, supplied by Shasta County Air Pollution Control District.

If attention be focused on the City of Redding which has about one fifth of the population of the entire county, a somewhat different picture emerges. Table IV-6 shows estimates of mobile source emission indices (normalized to unity for 1970), derived as explained above (Section IV-B1). By this measure, hydrocarbon emissions from traffic in the immediate vicinity of Redding increased by 12 percent between 1970 and 1974, while nitrogen oxides showed an increase of 22 percent by 1973, falling off in 1974 to 16 percent above the 1970 value. These increases apparently stemmed from a rather rapid increase of automobile traffic in the Redding vicinity. There was no sign of any striking change in emissions from stationary sources during these years.

Thus, while the county-wide estimates indicate a substantial decrease in total hydrocarbon emissions and a somewhat smaller decrease in emission of oxides of nitrogen, there may have been increases in emissions of both pollutants within the immediate vicinity of Redding during the period 1970-1974.

3. Stockton and Modesto (San Joaquin Valley Air Basin)

The San Joaquin Valley Air Basin is represented in this review by two cities, both a few miles east of the adjacent San Francisco Bay Area Air Basin: Stockton, in San Joaquin County, and Modesto, in Stanislaus County.

Emission inventory estimates for these two counties have been provided by the California Air Resources Board for each year of the pentad, 1970 to 1974, except 1971. These estimates are shown in Table IV-7 for San Joaquin County, and in Table IV-8 for Stanislaus County.

These counties are both primarily agricultural and they show quite similar emission patterns, with San Joaquin County emissions on the whole about 50 percent larger than those of Stanislaus County.

TABLE IV-6

MOBILE SOURCE EMISSION INDICES, REDDING
(SHASTA COUNTY, SACRAMENTO VALLEY AIR BASIN)

	tons per day				
	1970[a]	1971	1972	1973	1974
Hydrocarbons	1.00	1.01	1.01	1.05	1.11
Oxides of Nitrogen	1.00	1.10	1.13	1.22	1.16

[a] Normalized to 1970 = 1.00

TABLE IV-7

POLLUTANT EMISSIONS BY YEAR, SAN JOAQUIN COUNTY
(SAN JOAQUIN VALLEY AIR BASIN)

	tons per day			
	1970[a]	1972[b]	1973[b]	1974[c]
Hydrocarbons, Total	117	83	72	77
Stationary sources	41	30	37	42
Mobile sources	71	53	35	35
Percent mobile sources	63	64	49	46
Oxides of Nitrogen, Total	46	49	50	51
Stationary sources	8	7	9	9
Mobile sources	38	42	42	42
Percent mobile sources	82	85	83	82
Ratio, HC(Total)/NO_x(Total)	2.4	1.7	1.4	1.5

[a] Source, California Air Resources Board

[b] Source, California Air Resources Board, Preliminary Data

[c] Source, San Joaquin County Emission Inventory

TABLE IV-8

POLLUTANT EMISSIONS BY YEAR, STANISLAUS COUNTY
(SAN JOAQUIN VALLEY AIR BASIN)

	tons per day			
	1970	1972	1973	1974
Hydrocarbons, Total	70	63	54	50
Stationary sources	21	25	29	24
Mobile sources	49	38	26	26
Percent mobile sources	70	60	48	52
Oxides of Nitrogen, Total	30	34	36	35
Stationary sources	4	4	5	5
Mobile sources	26	30	31	29
Percent mobile sources	85	88	86	85
Ratio, HC(Total)/NO_x(Total)	2.3	1.8	1.5	1.4

Hydrocarbon emissions from all sources decreased by about 30 percent in each county, between 1970 and 1974; the hydrocarbon contribution from mobile sources decreased by about 50 percent in each county during that time, while the stationary source emissions showed no consistent trend in either county. As a consequence, the fraction of hydrocarbons attributable to mobile sources declined appreciably in both counties.

Emissions of oxides of nitrogen increased slightly in both San Joaquin County and Stanislaus County between 1970 and 1972, then levelled out, with very little change between 1972 and 1974. The fraction attributable to mobile sources was between 82 and 85 percent for San Joaquin County and slightly higher -- between 85 and 88 percent -- for Stanislaus County. Ratios of hydrocarbon emissions to oxides of nitrogen emissions decreased in a similar fashion in both counties, falling from about 2.4 in 1970 to about 1.4 in 1974.

Estimated mobile sourcee indices for the cities of Stockton and Modesto, calculated as explained in Section IV-B1, are shown in Table IV-9. Here, the differences between the two localities are a little more obvious. Motor vehicle traffic in the Stockton vicinity increased sharply in 1972 after a new freeway link was opened, causing increases in mobile source emissions, which were not paralleled in Modesto. Accordingly, over the four-year interval, hydrocarbon emissions from motor vehicles decreased by 15 percent in Modesto, but by only 2 percent in Stockton.

Emissions of oxides of nitrogen showed even greater divergence, as the table indicates. In Stockton, the emissions rose sharply to a peak in 1973, 25 percent above 1970; in Modesto, emissions rose slightly until 1972, then decreased more sharply to a new low in 1974 about 8 percent less than in 1970.

Neither city appears to have been much affected by changes in emissions from stationary sources during this period. In the Modesto area, a single large manufacturing plant emitting solvent vapors at

TABLE IV-9

MOBILE SOURCE EMISSION INDICES, TWO CITIES IN SAN JOAQUIN VALLEY AIR BASIN

	1970[a]	1971	1972	1973	1974
Hydrocarbons, Stockton	1.00	0.95	0.98	1.01	0.98
Modesto	1.00	0.97	0.94	0.90	0.85
Nitrogen Oxides, Stockton	1.00	1.04	1.12	1.25	1.15
Modesto	1.00	1.05	1.05	1.03	0.92

[a] normalized to 1970 = 1.00

the rate of about 2 tons per day was subjected to emission controls, which became operational only late in 1974.

Each city is credited with a population of about 35 to 40 percent of the entire county population. San Joaquin County had about 300,000, Stanislaus County about 200,000 residents during the period discussed here. Aside from these population differences and the roughly proportional differences in emissions, the two areas can be considered as having similar activities and emission patterns.

4. Salinas (North Central Coast Air Basin)

Emission inventory estimates for Monterey County have been obtained from the Monterey Bay Unified Air Pollution Control District and from the California Air Resources Board. Table IV-10 shows these estimates for the years 1970 to 1974 except 1971, for hydrocarbons and oxides of nitrogen.

The estimates indicate that hydrocarbon emissions, on the whole, increased dramatically during the period under study -- from 81 tons per day in 1970 to 178 tons per day in 1974. These estimates may not be taken at face value, however, because the basis for estimation changed after 1972, to reflect newly recognized emissions from a producing oil field in the Salinas Valley. In fact, it is probable that the emissions of hydrocarbons from this source were of the same order of magnitude before they came to the attention of the control agencies as afterwards, and that the actual changes in emissions from year to year did not exceed about 20 tons per day, the apparent increase in hydrocarbons from recognized stationary sources between 1970 and 1972.

Emissions of oxides of nitrogen appear to have increased by about 30 percent between 1970 and 1972, and to have changed only slightly thereafter. Between 40 and 50 percent of these emissions seemed to be attributable to mobile sources in the county. Mobile source emissions in the immediate vicinity of Salinas have been estimated in terms of the mobile source index, derived as explained above (Section IVB-1).

TABLE IV-10

POLLUTANT EMISSIONS BY YEAR, MONTEREY COUNTY
(NORTH CENTRAL COAST AIR BASIN)

	tons per day			
	1970[a]	1972[a]	1973	1974
Hydrocarbons, Total	(81)	(91)	163	178
Stationary sources	(28)	(48)	135	138
Mobile sources	53	43	27	40
Percent mobile sources	(65)	(47)	16	23
Oxides of nitrogen, Total	59	76	77	72
Stationary sources	30	40	44	40
Mobile sources	29	36	32	32
Percent mobile sources	49	48	42	45
Ratio, HC(Total)/NO_x(Total)	(1.4)	(1.2)	2.1	2.5

a During the years prior to 1973, the inventories did not include emissions of hydrocarbons from a producing oil field in which steam injection was employed as an aid to oil recovery. In 1973 and 1974, the emissions from this source alone were estimated to be more than 100 tons per day. Parentheses in these columns indicate that the figures presented are probably erroneous.

Table IV-11 shows the estimated values of this index, normalized to unity for 1970 emissions. The table indicates that neither hydrocarbon emissions nor nitrogen oxides emissions deviated by more than 10 percent from the 1970 value during the next four years.

On the whole, the impression is gained that emissions of oxidant precursors were fairly constant during the study period, both in the immediate vicinity of Salinas and in Monterey County generally.

5. Lancaster (Los Angeles County Portion of Southeast Desert Air Basin)

Emission inventory information for the Los Angeles County portion of the Southeast Desert Air Basin has been obtained from the California Air Resources Board and from the Southern California Air Pollution Control District. Table IV-11 shows estimates for the years 1970, 1972, and 1973, with somewhat less detailed information for 1974.

The estimates indicate that hydrocarbon emissions decreased rather abruptly from 28 to 22 tons per day between 1972 and 1973, due to an even sharper drop in hydrocarbons from mobile sources. This decrease in mobile source hydrocarbons was apparently not accompanied by a corresponding drop in emissions of oxides of nitrogen from mobile sources. Except for 1970, the information on which Table IV-12 is based was furnished with the warning (from ARB) that it was unpublished, preliminary information subject to revision. Further, major organizational changes in the cognizant local agencies have recently been made. For these and other reasons, it seems likely that some of the entries listed in Table IV-12 are of relatively low reliability.

Mobile source emissions in the immediate vicinity of Lancaster have been estimated in terms of the mobile source index, derived as explained in Section IV B-1. Table IV-13 shows these values, normalized to unity for 1970 emissions, for both hydrocarbons and oxides of nitrogen. The table indicates that emissions of both pollutants from

TABLE IV-11

MOBILE SOURCE EMISSION INDICES, SALINAS
(MONTEREY COUNTY, NORTH CENTRAL COAST AIR BASIN)

	tons per day				
	1970[a]	1971	1972	1973	1974
Hydrocarbons	1.00	0.94	0.90	0.92	0.94
Oxides of Nitrogen	1.00	1.02	1.01	1.07	0.98

[a] Normalized to 1970 = 1.00

TABLE IV-12

POLLUTANT EMISSIONS BY YEAR, LOS ANGELES COUNTY PORTION OF SOUTHEAST DESERT AIR BASIN (LANCASTER AREA)

	tons per day			
	1970	1972	1973	1974
Hydrocarbons, Total	27	28	22	20
Stationary sources	5	6	10	
Mobile sources	22	22	11	
Percent mobile sources	81	78	52	
Oxides of Nitrogen, Total	11	12	13	11
Stationary sources	2	1	1	
Mobile sources	9	12	12	
Percent mobile sources	86	96	91	
Ratio, HC(Total)/NO_x(Total)	2.6	2.3	1.7	1.8

TABLE IV-13

MOBILE SOURCE EMISSIONS INDICES, LANCASTER
(SOUTHEAST DESERT AIR BASIN)

	tons per day				
	1970[a]	1971	1972	1973	1974
Hydrocarbons	1.00	0.89	0.73	0.73	0.72
Oxides of Nitrogen	1.00	0.96	0.82	0.83	0.78

[a] Normalized to 1970 = 1.00

mobile sources decreased rather markedly; hydrocarbons were down by 11 percent by 1971, 27 percent by 1972, and oxides of nitrogen decreased by 18 percent, mainly between 1971 and 1972. Since there are no known large stationary sources of these contaminants in the Lancaster vicinity, it seems likely that the trend of emissions in the Lancaster area was downward for the entire period under study. (This conclusion is also consistent with the information given in Table IV-12, aside from the question of its reliability.)

6. Denver, Colorado (Metropolitan Denver Air Quality Control Region).

Information about emissions in the Denver area is, at best, fragmentary. Annual reports provided by the Colorado Air Pollution Control Commission indicate that an emission inventory for the seven counties in the AQCR was carried out in the summer of 1971 and that supplementary information suitable for updating was obtained in 1974. Hydrocarbon emissions were thus assessed at 463 tons per day in 1971 (applicable to 1970) and at 412 tons per day three years later. Corresponding tonnages of nitrogen oxides were 277 and 247, respectively. For Denver County alone, estimates obtained from the Environmental Health Service put hydrocarbon emissions at 180 tons per day in 1969, 201 in 1970, and 194 in 1971 and subsequently.

Taken at face value, these estimates suggest that emissions of hydrocarbons were rising until about 1970, but decreased gradually from then to 1973. Emissions of oxides of nitrogen apparently decreased similarly from 1970 to 1973, but no information is available as to their status before 1970.

7. Philadelphia

Information about emissions of hydrocarbons and oxides of nitrogen for the Philadelphia area was furnished by the Philadelphia Department of Public Health, Air Management Services. The estimates are shown in Tables IV-14 and IV-15 for the years 1969 through 1973.

TABLE IV-14

HYDROCARBON EMISSIONS BY YEAR, PHILADELPHIA, PA.

	tons per day				
	1969	1970	1971	1972	1973
From Industrial Processes	129	124	118	172	158
From Space Heating	21	22	20	20	18
From Power Generation	2	2	3	3	2
From Refuse Incineration	31	31	31	5	5
From Transportation	351	337	329	278	232
From Gasoline Handling[a]	(18)	(18)	(18)	18	18
From Non-industrial Solvents[a]	(7)	(7)	(7)	7	7
Total	559	541	526	503	440

[a] Entries for these categories in years 1969 through 1971 were not given in original inventories, but supplied by PES to maintain comparable totals.

TABLE IV-15

NITROGEN OXIDE EMISSIONS BY YEAR, PHILADELPHIA, PA.

	tons per day				
	1969	1970	1971	1972	1973
From Industrial Processes	24	24	22	40	37
From Space Heating	98	107	99	98	89
From Power Generation	98	98	119	103	89
From Refuse Incineration	3	3	3	3	3
From Transportation	90	93	96	111	112
Total	313	325	339	355	330

TABLE IV-15

NITROGEN OXIDE EMISSIONS BY YEAR, PHILADELPHIA, PA.

	tons per day				
	1969	1970	1971	1972	1973
From Industrial Processes	24	24	22	40	37
From Space Heating	98	107	99	98	89
From Power Generation	98	98	119	103	89
From Refuse Incineration	3	3	3	3	3
From Transportation	90	93	96	111	112
Total	313	325	339	355	330

For hydrocarbons, Table IV-14 indicates a generally declining emission rate. The inventory basis was altered slightly, beginning with the 1972 accounting, when 26 tons per day of emissions from gasoline handling and from non-industrial use of solvents were recognized and added in. Assuming similar contributions from these categories in the earlier years, the successive annual totals give a uniformly decreasing sequence, with a substantially greater drop between 1972 and 1973 than earlier years.

Nitrogen oxides emissions, in contrast, showed a generally increasing emission rate from 1969 to 1972, falling off slightly in 1973.

Regarding the comparisons of these totals from year to year, the Air Management Services report warns, "Due to variations in ... methods and response...it would be unwise to draw fine-point distinctions from emission estimate differences. Each revised emission factor publication usually contains more accurate values as more information and experience are obtained. Consequently, changes between inventories may be due to revisions in emission factors which may be greater than changes in actual emissions...unqualified interpretations are not recommended particularly between emissions and air quality data."

Despite the Air Management Services' conscientious explanations, the data presented in Tables IV-14 and IV-15 are the only data available for estimating the trends and they are, in all probability, no less accurate than data from the other jurisdictions represented in this report. Accordingly, it is reasonable to take these data at face value for the present purpose, as indicating the existence of a negative trend in hydrocarbon emissions and a positive trend in nitrogen oxide emissions over the period 1969 through 1973.

C. COMPARISON BETWEEN OXIDANT TRENDS AND EMISSION TRENDS, 1970-1974

1. San Francisco Bay Area

As noted in Section III-B, photochemical oxidant levels in the San Francisco Bay Area exhibited a significantly downward trend when data from nine stations, expressed in terms of yearly second highest daily maximum, were pooled. Hydrocarbon emissions also declined substantially over the pentad, 1970 to 1974, as discussed in Section IVB-1. The correlation coefficient between these quantities, pooled second-high oxidant level and regionwide hydrocarbon emissions, was 0.58, positive but not significantly greater than zero in view of the small number (5) of data points.

This low degree of correlation is not very surprising in view of the expected effects of various other factors (besides hydrocarbon emissions) on the development of photochemical oxidants. Chief among these factors are emissions of oxides of nitrogen, weather variations, and effects of geography and terrain.

Since oxides of nitrogen (along with hydrocarbons) are precursors of oxidants, it was of interest to explore correlations of the oxidant levels with emissions indices which might combine the effects of hydrocarbons and oxides of nitrogen. When the index used was the total emissions of both pollutants, the correlation coefficient was 0.60 -- practically unchanged. When the ratio of total hydrocarbons to total oxides of nitrogen emissions was tested, the correlation coefficient was found to be 0.88, a value significant at the 5 percent level. A correlation coefficient of 0.87, also significant, was obtained when the emissions index was taken as the difference between hydrocarbon emissions and oxides of nitrogen emissions.

These findings are especially interesting in view of the known chemical effects of nitric oxide on generation of oxidant in irradiation chamber experiments, where it is generally found that an excess of nitric oxide tends to retard the accumulation of ozone,

even though it may lead eventually to higher ozone levels. If this retardant effect were predominant in the atmosphere, a positive correlation between oxidant levels and the HC/NO_x ratio would be expected. Also, if this were the case, it would imply that decreasing emissions of oxides of nitrogen should be expected to have little effect in reducing oxidant levels, and might even tend to increase them. The correlation between oxidant level and nitrogen oxides emissions was -0.55, negative but not significant.

In any event, these results show that a large fraction of the variability in oxidant air quality from year to year can be accounted for in terms of the effects of varying rates of emissions, where both hydrocarbons and nitrogen oxides emissions are recognized as contributing factors. Emissions data are not readily available in sufficient detail to permit testing these correlations for the various monitored localities within the Bay Area Air Pollution Control District but it seems unlikely that stronger associations would be found, because of the known tendency for the primary contaminants, once emitted, to travel for many miles before oxidant peaks are generated. This aspect of the system is discussed in a later section of this report.

2. Denver

The information reported in Section III-C indicates that oxidant air quality at one station in Denver, expressed in terms of the average daily maximum oxidant concentration for each year, decreased steadily between 1968 and 1973, at an average rate of 0.0033 ppm per year. Available information on emissions of hydrocarbons and oxides of nitrogen is not sufficiently detailed to establish whether a comparable reduction in emissions took place at the same time.

In the Metropolitan Denver Air Quality Control Region, hydrocarbon emissions are reported to have decreased from 463 tons per day in 1971 to 412 tons per day in 1974, an average of about four percent per year. Oxides of nitrogen emissions are said to have decreased from

277 to 247 tons per day in the same period, an average of almost four percent per year. For Denver County alone, emissions have been reported as increasing from 180 tons per day in 1969 to 194 tons per day in 1971, an average increase of four percent per year. These figures show no apparent relation to the oxidant air quality trend indicated above.

During the interval from 1971 to 1974, average daily traffic at the intersection nearest to the monitoring station increased by only six percent, or two percent per year. This stability could account, in part, for the observed oxidant trend, if the hydrocarbon emission factors for motor vehicles were decreasing during the same period. A simultaneous increase in motor vehicle emission factors for oxides of nitrogen could enhance this effect. However, these conditions were probably not achieved until after 1971, whereas the observed oxidant trend covers a longer period, starting three years earlier. Thus, although plausible ad hoc explanations for the oxidant trend may exist, the available data base is insufficient to confirm any of them.

3. Other Areas Included in Study

As shown in Chapter III, none of the individual oxidant trends were found to be significant except in the San Francisco Bay Area and the Denver area, already discussed in previous sections. Since these individual trends were not significant, a detailed comparison with emissions trends would not be especially useful. However, if the trend direction for air quality agrees with the trend direction for emissions in a large enough proportion of the cases studied, this would constitute additional support for the hypothesis that reduction of emissions should lead to improved oxidant air quality.

Table IV-16 shows the matrix of trend directions for various emissions indices and air quality indices for the six locations not already discussed more fully. Cursory inspection shows that there is

TABLE IV-16

TREND DIRECTIONS FOR VARIOUS EMISSIONS INDICES AND VARIOUS AIR QUALITY INDICES, FOR FIVE CALIFORNIA LOCATIONS AND PHILADELPHIA

	location					
	RD	ST	MO	SA	LN	PH
Hydrocarbon emissions	-	-	-	0	-	-
Mobile Source Index	+	0	-	-	-	
Nitrogen Oxide emissions	-	+	+	+	-	
Yearly second high Ox	0	+	-	+	+	+
Average maximum Ox	+	+	-	+	+	+
3rd Qtr Average max. Ox	+	+	-	+	+	+
Frequency, Ox > 0.08ppm	+	+	-	+	+	-

Locations: RD, Redding, CA
ST, Stockton, CA
MO, Modesto, CA
SA, Salinas, CA
LN, Lancaster, CA
PH, Philadelphia, PA

no general agreement as to trend direction, between any of the emissions indices and any of the air quality indices as listed. Thus the matrix in toto furnishes no more support for the hypothesis of a connection between emissions and air quality than can be found by an examination of the individual cases.

D. REVIEW OF LONG-TERM TRENDS, SAN FRANCISCO BAY AREA

Assessment of a trend in air quality in any given region is likely to be complicated by the variations in weather conditions from year to year, which may be expected to cause fluctuations in the air quality indices, even in the absence of any change in emission inventories. Even trends which have been evaluated as statistically significant are not necessarily caused by reductions in emissions, since weather trends might conceivably have the same effect. The longer the period of observation is, the less is the likelihood of a sustained trend due to weather factors alone. A five-year period, however, is not long enough to rule out the appearance of air quality trends unrelated to abatement of pollutant emissions.

In relation to photochemical oxidant levels, the main weather factors expected to cause important effects are wind, sunshine, and atmospheric stability -- the existence and height of a mixing layer. In any given situation, the development of high concentrations of oxidants is favored by low wind speeds, bright sunshine, and low mixing heights (i.e., low inversions).

In studies of oxidant levels using a data base going back to 1954, the Technical Services Division of the San Francisco Bay Area Air Pollution Control District has observed that daily maximum temperatures tend to reflect both sunshine intensity and limited ventilation. Thus the days with weather most conducive to oxidant formation are also days on which the maximum temperature falls within some readily discernible range. The Division has made use of this observation in formulating criteria for selecting days of comparable weather to refine the detection of weather-independent oxidant trends.

To further sharpen the definition of comparable days, the Division added a criterion reflecting vertical dilution, namely, an inversion base within a certain height limit at a given time of

day. They then investigated the oxidant levels attained on all days meeting these criteria over the 13-year period, 1962 through 1974.

Table IV-17 shows the results of this analysis, for one station in each of the original six counties of the District. The index for the six stations combined declined from values of 0.12 and 0.13 ppm in the period 1962 to 1965 to values of 0.08 and 0.09 in the period 1970 through 1974. Although the trends at the individual stations were not completely parallel to the general trend, all reflected the general trend to an appreciable extent.

Specifically for the period 1970 to 1974, a downward trend is evident for all of the original six stations except San Jose, which registered a new high for the pentad of 0.16 ppm in 1974. Table IV-18 shows how the trends indicated by the Division's analysis compare with those identified in Section III-G (Table III-6) for the stations common to both analyses. The Division's index, for these five stations, agrees with the index based on frequency of oxidant values exceeding 0.08 ppm in showing positive trends at San Jose and Livermore and negative trends at the other three locations.

As reported above (Section III-H), trend magnitudes for the Bay Area for the last five available years were, for the most part, found to be not statistically significant. The test involves the Student t statistic, as explained by Moroney;[2] with only 5 points to establish a trend, a high correlation coefficient, 0.88 or larger, is needed. With more years of data, trends may be significant even though accompanied by much lower correlation coefficients. Figure IV-1 illustrates the relation between the number of points available and the correlation coefficient needed for significance at the 5 percent level. With eight points, coefficients above 0.71 are significant; with thirteen points, coefficients above 0.55 are significant.

TABLE IV-17

AVERAGE HIGH-HOUR OXIDANT CONCENTRATIONS FOR DAYS WITH COMPARABLE TEMPERATURE AND INVERSION CONDITIONS. (APRIL THROUGH OCTOBER OXIDANT SMOG SEASONS, 1962-1974)
(Source: Information Bulletin 3-25-75: A Study of Oxidant Concentration Trends: Technical Services Division, Bay Area Air Pollution Control District.)

Monitoring Station	Average High-Hour Oxidant Concentration (KI parts per million)													13-yr
	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72	'73	'74	
San Francisco	.14	.12	.15	.09	.08	.08	.05	.04	.07	.05	.03	.04	.05	.08
San Leandro	.13	.16	.19	.19	.14	.12	.11	.12	.12	.11	.10	.11	.10	.13
San Jose	.11	.17	.14	.16	.11	.13	.13	.13	.12	.08	.10	.11	.16	.13
Redwood City	.13	.10	.10	.14	.10	.09	.08	.09	.08	.07	.08	.07	.07	.09
Walnut Creek	.10	.11	.10	.11	.10	.13	.10	.13	.09	.09	.09	.08	.08	.10
San Rafael	.08	.09	.07	.08	.07	.07	.06	.07	.08	.07	.05	.06	.06	.07
BAAPCD Average*	.12	.12	.13	.13	.10	.10	.09	.10	.09	.08	.08	.08	.09	.10
Livermore**	--	--	--	--	--	.13	.18	.18	.13	.11	.09	.12	.13	.13

* For benchmark stations above, with 13 years of record.
** Station with 8 years of record.

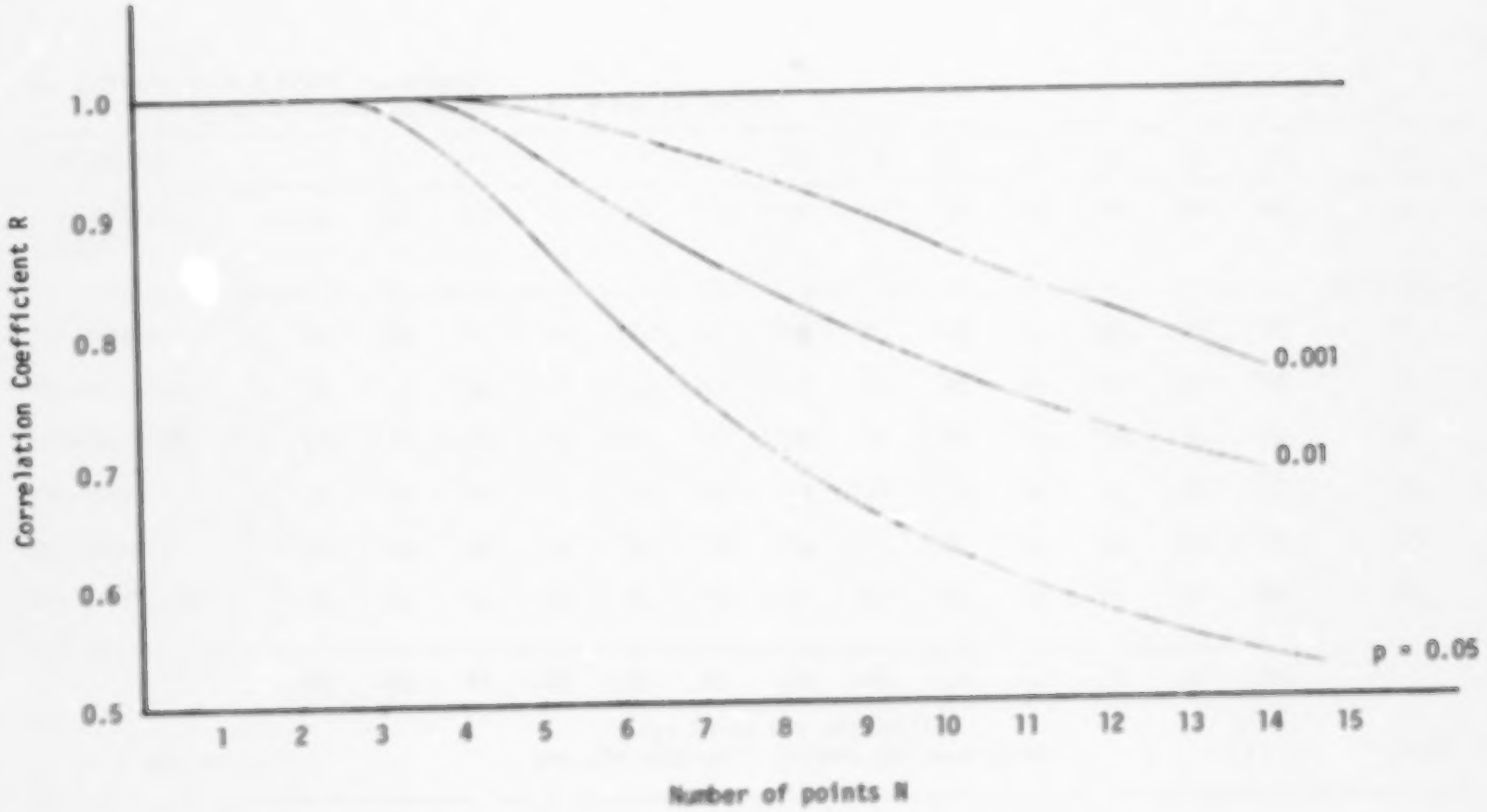

Figure IV-1. Smallest value of correlation coefficient significantly different from 0 at p = 0.05,0.01,0.001 (two-way test), for a data base of N points. (Number of degrees of freedom = N-2)

Using the data shown in Table IV-17, tests for significance were made on various subsets of the data. When the data for all six stations having a 13-year record were pooled, the correlation coefficient was -0.880, which is significant at the 0.1 percent level; thus, there is no question that oxidant air quality for the Bay Area District has improved since 1962. Again, when the data for all seven stations having an 8-year record were pooled, the correlation coefficient was -0.741, significant at the five percent level. Over periods ending in 1974 but shorter than eight years, significant correlations were not found, mainly because of the sharp upturn observed at San Jose in 1974. (With San Jose omitted, the remaining six stations showed a significant trend for the six-year period, 1969 through 1974.)

Since it was clear that hydrocarbon emissions had been on the decline in the Bay Area District for several years, it was of interest to test correlation of oxidant air quality levels against emissions for the corresponding years. Accordingly, estimates of hydrocarbon emissions were taken from a recent tabulation (BAAPCD Emission Trends Report, Base Year 1974, issued Feb. 6, 1976) and used in a correlation analysis. When these emissions data (Table IV-19) were paired with pooled oxidant air quality data for six stations (Table IV-17) for 13 years, the correlation coefficient was +0.767, significant at the 5 percent level and higher than the value (0.58) found for correlation between hydrocarbon emissions and yearly second-high oxidant, 1970 to 1974 (Section IV-C-1).

Again, indices combining the effects of emissions of hydrocarbons and nitrogen oxides were tested. When the index used was the total of both pollutants, there was no appreciable correlation ($r = -0.16$). When the ratio of hydrocarbon emissions to nitrogen oxide emissions was tested, the coefficient was found to be 0.92, significant at the 0.1 percent level. An index in which the oxides of nitrogen emissions were subtracted from hydrocarbon emissions (on

TABLE IV-18

TREND DIRECTIONS FOR VARIOUS OXIDANT INDICES
SHOWN AT VARIOUS MONITORING STATIONS,
SAN FRANCISCO BAY AREA.

	SF	RC	SJ	SL	LV
Average max on comparable days	-	-	+	-	+
Yearly second high maximum	-	-	+	-	-
Yearly average maximum	-	+	+	+	+
Third quarter average maximum	-	-	+	+	+
Frequency > 0.08ppm	-	-	+	-	+

Locations: SF, San Francisco
RC, Redwood City
SJ, San Jose
SL, San Leandro
LV, Livermore

TABLE IV-19

ESTIMATED EMISSIONS BY YEAR, SAN FRANCISCO BAY AREA AIR POLLUTION CONTROL DISTRICT, 1962-1974, AND COMBINED EMISSION INDICES, FOR HYDROCARBONS AND OXIDES OF NITROGEN.

tons per day

Year	HC	NO_x	$(HC+NO_x)$	(HC/NO_x)	$(HC-NO_x)$
1962	1300	490	1790	2.65	810
1963	1300	500	1800	2.60	800
1964	1400	550	1950	2.55	850
1965	1300	550	1850	2.36	750
1966	1300	620	1920	2.10	680
1967	1300	620	1920	2.10	680
1968	1300	670	1970	1.94	630
1969	1300	700	2000	1.86	600
1970	1140	740	1880	1.54	400
1971	1110	740	1850	1.50	370
1972	1130	790	1920	1.43	340
1973	1070	820	1890	1.30	250
1974	1030	720	1750	1.43	310

a ton-for-ton basis) gave correlation coefficient 0.892, also significant at the 0.1 percent level. The coefficient of correlation between oxidant level and nitrogen oxides emissions alone was, in this analysis, -0.91; this is nearly as large as the coefficient cited above in which hydrocarbons were included, and is equally significant.

These results reinforce those discussed in Section IV-C-1 in a very satisfactory way. The correlation coefficients obtained with the use of a relatively weather-independent oxidant index turn out to be of the same order of magnitude as, but slightly higher than, those found for the yearly second-high, an index more sensitive to weather. More important, the trends shown to be marginally significant when assessing data for five years (1970 to 1974) are found to be very convincing when data for 13 years are available. The fact that the correlation coefficient is larger for oxides of nitrogen emissions than for hydrocarbon emissions may be due to the larger relative range of the oxides of nitrogen emissions during the period under study. It should not be construed as proving that the influence of hydrocarbons on oxidant levels is necessarily small relative to the influence of oxides of nitrogen, since there is certainly a substantial degree of confounding between these two nominally independent variables--the correlation between them is -0.79, significant at the 0.01 level.

REFERENCES

1. A. Ranzieri, Personal Communication

2. M. J. Moroney, "Facts From Figures," 3rd Edition, p. 311. Penguin Books. Baltimore, Maryland, 1956.

V. INTERACTIONS WITH WEATHER AND OTHER FACTORS

A. SAN FRANCISCO BAY AREA, WEATHER VARIABLES

Although the correlations described in Sections IV-C and IV-D have demonstrated the existence of a statistically significant relationship between oxidant air quality and precursor emissions, on an annual basis, it is nevertheless of interest to investigate whether there may also be a demonstrable relationship between oxidant air quality and available weather variables, year by year. A convenient statistical tool for this purpose is rank correlation.

If changes in the weather from year to year can have an appreciable influence on air quality, as is commonly assumed, then it should be possible to show some degree of agreement between measured air quality indices and observed weather parameters, despite the relatively long-term trends in contaminant emissions. From the BAAPCD Information Bulletin of 3-25-75, we have records of the number of days judged conducive to smog in the District's study of oxidant concentration trends. These may evidently serve as a rough indication of the joint effect of relevant weather parameters.

For the seven stations treated in the Bulletin, the average numbers of smog-conducive days reported in the successive years 1970 to 1974 were 46.3, 45.0, 36.7, 42.0 and 44.3, respectively. Thus the ranking of these years with respect to smog conduciveness was 1, 2, 5, 4, 3. The various annual oxidant indices were tested for agreement with this order for each of the nine air monitoring stations included in this study. The results, in terms of rank correlation coefficient, are shown in Table V-1.

The correlation coefficients found range from + 0.8 to -0.5. Individually, none of these is statistically significant at the five percent level, since the minimum value for significance with N=5 is 0.87. Cumulatively, however, these results show convincing significance

TABLE V-1. RANK CORRELATION COEFFICIENTS BETWEEN VARIOUS ANNUAL OXIDANT INDICES AND AVERAGE NUMBER OF SMOG-CONDUCIVE DAYS, FOR YEARS 1970 TO 1974

INDEX	STATION									
	SF	RC	SJ	FR	SL	OK	RI	PT	LV	AVG.
Second High	.6	.5	-.5	0	.8	.7	.7	.4	.7	.4
Average Maximum	.3	-.2	.5	-.2	.5	.3	.5	.3	.5	.3
3rd Quarter Average	.4	-.3	.2	.5	.6	.8	.7	.4	.5	.4
Frequency >0.08	.7	.4	.4	-.1	.7	.8	.5	.6	.5.	.5

for each oxidant index, as the number of values greater than zero is seven or eight out of nine in each case. (Tables of the Binomial Distribution indicate that the probability of eight positive values being obtained by chance is only 0.02; the probability of seven, 0.09). Thus, it is statistically reasonable to assert that annual oxidant air quality in the Bay Area is sensitive to differences in weather from year to year, as well as to changes in pollutant emissions.

A further point of interest is to what extent oxidant air quality may be related specifically to temperature differences from year to year, in view of the fact that photochemical smog is generally associated with sunny, warm weather. Table V-2 shows the results of rank correlation, based on average maximum temperatures recorded at the San Francisco station. (Temperatures from the Oakland Airport also give the same results, since the ranking of years is the same for the two locations, namely, 2, 1, 3, 5, 4. The rank correlation between these temperatures and the number of smog-conducive days, however, is only 0.5.)

The coefficients for these correlations range from + 0.9 to -0.9. There is, again, a significant tendency toward positive correlations, although it is not as consistent as for the correlations with the smog-conducive days. In particular, the average maximum index (i.e., the average daily high-hour value for the entire year) shows no detectable tendency to be correlated with these maximum temperatures. These results suggest that, on the whole, the index of smog-conduciveness developed by the Bay Area Air Pollution Control District is a substantially better smog-predicting variable than is temperature alone. They tend to confirm the utility of the District's approach, in which a criterion of vertical dilution is added to the temperature criterion for defining smog-conducive days. According to the District's Information Bulletin (loc. cit.), "The addition of the inversion criterion

TABLE V-2. RANK CORRELATION COEFFICIENTS BETWEEN VARIOUS ANNUAL OXIDANT INDICES AND ANNUAL AVERAGE MAXIMUM TEMPERATURE IN DOWNTOWN SAN FRANCISCO, FOR YEARS 1970 TO 1974

INDEX	STATION									
	SF	RC	SJ	FR	SL	OK	RI	PT	LV	AVG.
Second High	.7	.5	-.9	.6	.6	.7	.7	.9	.3	.5
Average Maximum	-.1	.1	-.3	-.2	-.3	-.1	.5	.4	-.3	0
3rd Quarter Average	.6	.4	-.5	.7	.3	.7	.4	.7	-.3	.3
Frequency ≥.08	.2	.9	-.3	-.3	.2	.6	.5	.8	-.3	.3

eliminates some of the anomalous cases in which heating actually destroys the inversion and results in low oxidant maxima because of vertical dilution."

Scrutiny of Table V-2 reveals that two stations showing most of the negative correlations are San Jose and Livermore. These stations also yielded anomalous results in the BAAPCD study (loc. cit.), leading the District to explore the relevance of local wind speed and direction as variables which might further improve oxidant prediction. This exploration yielded the conclusion that the local wind factor could account for a significant part of the increase in oxidant level observed at San Jose in 1974.

B. GEOGRAPHICAL EFFECTS, BAY AREA AND CENTRAL VALLEY

The geographical variation in oxidant air quality in three of the air basins discussed in this report are most easily discussed and interpreted in terms of a single meteorological system, whose general nature is seen in Figure V-1.

During much of the year, especially during the summer months when high oxidant levels are common, the prevalent flow of air is onshore, into the Bay Area through the Golden Gate (the entrance to San Francisco Bay) and eastward into the Central Valley via San Pablo Bay, Carquinez Strait, Suisun Bay and the delta of the Sacramento and San Joaquin Rivers. Within the Bay Area, part of this flow is diverted northward into the Sonoma and Napa Valleys and southward into the Santa Clara and Livermore Valleys. In the Central Valley the main flow is bifurcated, ventilating the Sacramento Valley to the north and the San Joaquin Valley to the south.

As in other California Coastal areas, the subsidence inversion dominates this wind field for a large part of the year, varying seasonally between about 300 and 1,000 meters elevation. Due to

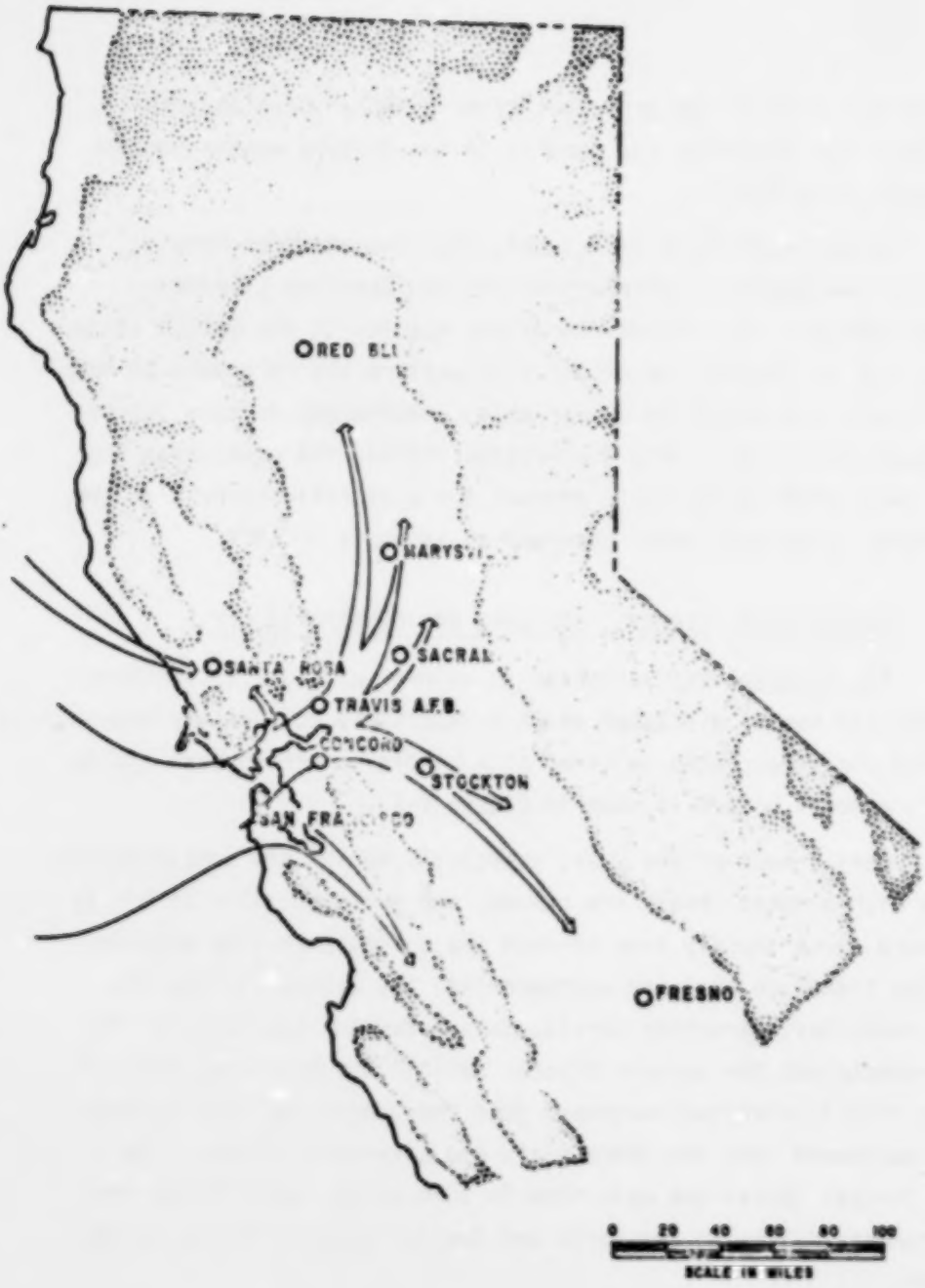

FIGURE V-1. NORMAL FLOW PATTERN IN THE SUMMERTIME MARINE LAYER
(Source: S. J. Savage, 1967)

solar heating the inversion is sometimes destroyed over the downwind, up-valley extremes of these valleys, and wide variations in the extent of vertical mixing characterize these locations even when the inversion persists.

The meteorology and climate of the Central Valley are especially conducive to air pollution. Photochemical smog in the summer and early fall is enhanced by an almost unbroken succession of warm, sunny days. In the Bay Area, summer sun is often moderated by the presence of stratus, reducing insolation until late in the morning. This effect is greatest near the main channel of flow of the marine air, whereas isolated valleys such as the Napa, Livermore, and Diablo Valleys tend to be warmer and sunnier.

This study has related to oxidant air quality as measured at nine monitoring stations in the Bay Area, one in the Sacramento Valley, and two in the San Joaquin Valley, as described in Chapter II. Rankings of the twelve stations relative to four different indices of air quality are shown in Table III-7, from which it can be seen that the oxidant problems in inland valley locations are, on the whole, more severe than those in the populous industrial areas fronting the Bay.

Dividing the twelve stations into these two categories, we find the inland-type stations best represented by Fremont, San Jose, and Livermore in the Bay Area and the Central Valley locations, Redding, Stockton and Modesto. The remaining stations, San Francisco, Redwood City, Oakland, San Leandro, Richmond and Pittsburg, are predominantly industrial, bayside communities. Using the annual second-high oxidant as the air quality index, five of the valley locations appear to be among the six most affected; using any of the other indices, the valley locations are the six most affected.

Two stations, Redding and Modesto, rank much lower by the second-high statistic than by the other three indices. These stations are both far downwind of the Bay Area; Redding is 300 km. to the north, Modesto about 100 km. to the south. Especially in Redding, there is little local industry and a sparse population. It is striking, therefore, that this area has relatively high oxidant levels and high frequency of exceeding the NAAQS. In all probability, these levels predominantly result from transport of the polluted marine air along the track indicated in Figure V-1. (Note that Redding is some 50 km. north of Red Bluff, the city shown on the map.)

On the other hand, two stations, Fremont and San Leandro, rank much higher by the second-high statistic than by the other indices. San Leandro is an industrial area near the Bay, and Fremont a nearby residential area only about 15 km. farther inland; their high-oxidant episodes probably occur mainly in less typical air flow situations when the ventilation of the east Bay Area by the sea breeze is relatively weak.

Stockton and Pittsburg represent intermediate cases. Although fairly well inland, Stockton is only a few kilometers from the delta area and is well ventilated by the up-valley wind from the Bay Area. Pittsburg is on the waterfront and in the marine air stream which later ventilates the valley. Stockton and Pittsburg are therefore, to an appreciable extent, protected from both the long-distance transport that delivers oxidants to Modesto and Redding and from the local stagnation episodes that occasionally afflict Fremont and San Leandro.

The relatively low rankings of the remaining locations--San Francisco, Oakland, Richmond and Redwood City--provide unmistakable evidence that the maximum effect of oxidant precursors is not to be found in the area where the contaminants are emitted,

but at various downwind locations. One principal reason for this state of affairs is the dual role of nitric oxide as both a precursor and an inhibitor of the oxidant-forming process. The industrial and vehicular sources of this precursor furnish a necessary constituent for oxidant formation, but one which ensures that the air will have long since moved to another location by the time its oxidant potential becomes manifest.

VI. SUMMARY AND CONCLUSIONS

A study of the relation between oxidant air quality and emissions of oxidant precursors (hydrocarbons and oxides of nitrogen) has been made, utilizing data from five or more recent years of ambient air monitoring. Areas investigated were:

- in California,
  1. the San Francisco Bay Area, represented by monitoring sites at San Francisco, Redwood City, San Jose, Fremont, San Leandro, Oakland, Richmond, Pittsburg, and Livermore
  2. the northern Sacramento Valley Air Basin, represented by Redding, Shasta County
  3. the northern San Joaquin Valley Air Basin, represented by Stockton, San Joaquin County, and Modesto, Stanislaus County
  4. the North Central Coast Air Basin, represented by Salinas, Monterey County
  5. the Southeast Desert Air Basin, represented by Lancaster, Los Angeles County.
- in Colorado, Denver City and County, part of the Metropolitan Denver Air Quality Control Region.
- in Pennsylvania, Philadelphia City and County, part of the Metropolitan Philadelphia Interstate Air Quality Control Region.

These areas ranged in demographic character from sparsely populated agricultural and desert communities to densely populated metropolitan areas. Geographically, they represented the Atlantic Seaboard, the Rocky Mountain area, and the Pacific Coast, with attention to coastal and interior locations in California. Industrial activity ranges from negligible to fairly intensive.

Meteorologically, the California vicinities are subject to the influence of the Pacific High, which causes a semi-permanent

subsidence inversion over most of the state. The Colorado and Pennsylvania cities reflect continental and seaboard meteorology.

Various air quality indices have been compiled and examined for evidence of trends. These include:

- 2nd high: the second highest daily high-hour oxidant value observed during a full year of observations at a single monitoring location.
- Average maximum: the average daily high-hour oxidant value for a year of observations.
- 3rd quarter average maximum: the average daily high-hour oxidant value for the months of July, August and September in any one year.
- Frequency >.08: the frequency, in percent of all days monitored, of days with oxidant values exceeding the NAAQS level (0.08 ppm) during a full year of monitoring at a single location.
- Frequency >.16: the frequency, in percent of all days monitored, of days with oxidant values exceeding 0.16 ppm during a full year of monitoring at a single location.

Most of the trends for individual stations, as evaluated for the five-year period, were not statistically significant at the 5 percent level. Forty-five pairs of corresponding values of these two indices (i.e., values for nine stations for five years) yielded a correlation coefficient of 0.73, highly significant. This trend was not paralleled by significant decreases in the other indices for the Denver area.

A substantial degree of independence between the 2nd-high statistic and the average maximum was indicated by comparisons of the trends at various monitoring stations. To explore the relations between the indices, correlation coefficients were computed for the Bay Area stations. For the entire data base, a highly

significant correlation was found. Taking the average maximum index as the independent variable, the regression coefficient was 3.3 and the standard error of estimate about 20 percent. These results tend to substantiate the utility of the 2nd-high index as a measure of oxidant air quality.

Calculation of coefficients of concordance among the four indices of oxidant air quality (frequency above 0.16 excluded) showed substantial agreement in the statistical sense (C=0.83), but also showed that the degree of agreement could be radically improved (C=0.99) by either excluding the 2nd-high index from the set tested or by excluding four of the twelve northern California monitoring stations (namely, Fremont, San Leandro, Modesto and Redding). The results confirm that excellent agreement between all indices, for any extensive set of monitoring locations, is not to be expected.

An analysis of variance of the 2nd-high statistics for the Bay Area stations showed that the yearly change effect was significant at the 5 percent level and that the differences between stations were significant at the 1 percent level. Error standard deviation was evaluated as 0.038 ppm. Because these differences are statistically significant, the effects cannot be accounted for as accidental variations, but require explanation in terms of the major variables intrinsic to the determination of air quality: emissions and weather.

Emissions and emission trends have been reviewed in detail for each of the selected study locations. For both hydrocarbons and oxides of nitrogen, the estimated emissions have been partitioned into those from stationary sources and those from mobile sources, and the year-to-year trends examined. In most locations, the predominant changes in hydrocarbon emissions were in the emis-

sions from mobile sources; especially in the rural areas, where mobile sources constitute the major part of the total. For California, mobile sources are discussed in terms of a "mobile source emission index," based on combining motor vehicle traffic information with appropriate motor vehicle emission factors obtained from the California Air Resources Board.

For the San Francisco Bay Area, using as the annual oxidant index the pooled second-high statistics for the nine monitoring stations, correlations with annual total emissions were investigated. The correlation with total hydrocarbon emissions was positive (0.58) but not statistically significant at the 5 percent level. A similar result was obtained (0.60) using the total emissions of both hydrocarbons and oxides of nitrogen. However, there was high and significant correlation when the emissions of oxides of nitrogen were introduced as an inverse factor (0.88) or as a negative contribution (0.87).

These results show that a large fraction of the variability in oxidant air quality from year-to-year (as determined by the pooled second-high statistics for the San Francisco Bay Area)can be accounted for in terms of the effects of varying rates of emissions, where both hydrocarbons and oxides of nitrogen emissions are recognized as contributing factors.

In the Denver area, a confused picture on the evaluation of appropriate emissions trends prevents an adequate statistical test of the relation of the observed significant decrease of average maximum oxidant levels to emission totals. Hydrocarbon emissions have been increasing in Denver County, but decreasing in the Metropolitan Denver Air Quality Control Region. In the vicinity of the single monitoring station, motor vehicle traffic increased, while emission factors were generally decreasing. Plausible ad hoc explanations for the oxidant trend may exist, but the available data base is insufficient to confirm them.

For the other areas included in the study, a matrix of trend directions for various emissions indices and air quality indices showed no general agreements as to trend directions.

Using data on long-term oxidant trends from a special study carried out by the Bay Area Air Pollution Control District, the correlation of a weather-stratified oxidant index with annual emissions was tested, for the thirteen-year period 1962-1974. When the data for six stations having a thirteen-year record were pooled, the oxidant trend was significant at the 0.1 percent level. When these data were paired with hydrocarbon emissions for the Bay Area for the same period, the correlation coefficient was 0.767, significant at the 5 percent level and higher than the value (0.58) found in studying the 1970-1974 period (v.s.). Again, consideration of oxides of nitrogen emissions increased the degree and significance of the correlation. When these emissions were included as an inverse factor, the correlation coefficient was 0.92, significant at the 0.1 percent level. When the oxides of nitrogen emissions were taken as a negative contribution, the correlation coefficient was 0.89, also significant at the 0.1 percent level. These results, therefore, reinforce those obtained in studying the five-year data, discussed above.

Rank correlation studies showed that, in the Bay Area, the various annual indices of oxidant air quality significantly reflected changes in annual weather conditions as measured by the number of smog-conducive days per year (by Bay Area Air Pollution Control District criteria). The oxidant indices also reflected annual average maximum temperatures, but not as strongly or consistently as they reflected the frequency of smog-conducive weather.

Reviewing the relation of oxidant air quality to geographical factors within the single meteorological system comprising the

San Francisco Bay Area and the Central Valley, it is seen that oxidant problems are most severe at inland valley locations and least severe in populous, industrial Bayside communities. These conditions seem to be related to two principal factors: the superior ventilation of communities along the main waterfronts; and the inhibitory effect of the oxides of nitrogen emitted by industry and motor vehicle traffic. Both of these protective circumstances tend to fade as the marine air moves downwind to the inland valley locations.

To recapitulate, the main conclusions resulting from this project are:

1. Long-term trends in oxidant air quality in the San Francisco Bay Areas are significantly related to rends in hydrocarbon emissions.

2. Oxidant concentrations in the San Francisco Bay Area are inversely affected by oxides of nitrogen emissions; thus, reduction of these emissions tends to increase measured oxidant levels, on the whole.

3. In the San Francisco Bay Area, oxidant problems tend to be more severe in inland valley locations than in industrial, Bayside locations.

4. The oxidant air quality of communities in the Central Valley of Caifornia is appreciably affected by the flow of polluted marine air from the adjacent San Francisco Bay Area.

5. Monitoring data for a five-year period is not, in general, sufficient to establish statistically significant oxidant trends for individual monitoring stations.

6. A significant reduction of oxidant levels occurred in Denver during the period 1968-1973. This cannot be attributed with confidence to observed trends in emissions.

7. The second highest daily high-hour oxidant value for a single year at a single station is a statistically useful measure of oxidant air quality as shown by analysis of variance.